THE OFFICIAL MAGAZINE OF THE SOCIETY OF FIRE PROTECTION ENGINEERS

FIRE PROTECTION Engineering

FALL 2004

Issue No.24

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ALSO:

12 FIRE TESTING OF INTERIOR FINISH

18 THE ROLE OF INTERIOR FINISH IN FIRE DEVELOPMENT

29 ASSESSING THE BURNING CHARACTERISTICS OF INTERIOR FINISH MATERIAL

SFPE

FIRE PROTECTION **Engineering**

Fire Protection Engineering (ISSN 1524-900X) is published quarterly by the Society of Fire Protection Engineers (SFPE). The mission of *Fire Protection Engineering* is to advance the practice of fire protection engineering and to raise its visibility by providing information to fire protection engineers and allied professionals. The opinions and positions stated are the authors' and do not necessarily reflect those of SFPE.

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Cover photo: The Image Bank/Venetian Hotel & Casino, Las Vegas, Nevada

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Interior Designers Put Fire Protection into Practice

Interior designers are visionaries. They transform interior space from the intangible to the tangible – they introduce a new aspect, a new purpose, a new function. They see what is not yet there, and through their ability to convey their vision to the client, they are given the opportunity to make the vision a reality. They orchestrate the elements of space, color, texture, and scale, and apply them in new and different ways, creating desired outcomes for the client.

There is not one process, element, or task involved in the design of interior space that does not take into consideration the preservation of the health, safety, and welfare of human life: furniture is selected through knowledge of ergonomics; interior structure and furniture placement are determined through knowledge of accessibility needs, egress requirements, adjacency preferences; color schemes are determined through knowledge of their psychological impact on the human experience; wall and ceiling finishes are selected through knowledge of acoustics; floor finishes are selected through knowledge of performance, way-finding, and surfacing requirements; and lighting is selected through knowledge of ambient, task, and focal requirements.

Whether they specialize in office design, hotel design, restaurant design, healthcare design, residential design, etc., every individual element combines with the whole to create a cohesive unit that enriches the lives of the inhabitants and achieves the client's strategic goals.

Projects begin with the assemblage of information pertinent to the project. Once project goals and objectives are clearly outlined, the steps that lead the project to a successful completion are put in place. Parameters for design are drawn through careful communication and input from the end-user(s), the client, and other project team members.

Initially, research of all codes that pertain to the project are considered and applied to every element involved in the facilitation of the design: furniture, finishes and coverings, fixtures and equipment, accessories and decorations. This is comprehensive and time-consuming. It requires meeting with the local plan reviewers and/or code officials who preside in the jurisdiction where the project is located in order to understand together the full scope of the project, the goal of the design concept, and from that, interpret the intent of the codes. Their ultimate goal is to preserve life by retarding the spread of fire and smoke while occupants escape to safety.

Benchmarks for success are diverse: building and fire code compliance for life safety; ADA compliance to remove barriers for universal accessibility; sustainability in the selection of materials; adaptive reuse of existing space; green design for the preservation of natural resources; color and visual, tactile and audible details for improved health and well being; space planning for order and paths of egress; recyclability to reduce overflow in land fills; indoor air quality to prevent off-gasing that causes sick building syndrome; ease of maintenance – the list goes on.

It is not possible for code officials to be aware of every material specified by designers, so thoughtful interpretation is required for new products not yet addressed in the codes. This is the stuff of ongoing code development. Not only the product, but its specific application must be considered. For interior designers whose projects are located in numerous jurisdictions, whether by state, region, or nationally, the lack of one universal code compounds the research and paper trail documentation, not to mention the multiple finishes that differing code officials might require for clients with multiple projects in just as many locations.

In addition, building and fire codes are enforced by unique individuals who do not always share the same interpretation of the codes. Even two officials working in the same office can have differing judgments on a code's intent and application. Designers may choose to work exclusively with a single code official throughout their project, requesting documentation of the code interpretations in writing. For example, in some communities where CAL 117 has been adopted, compliance with CAL 133 can be required in certain situations, completely at the discretion of the code official.

Acquiring and compiling approvals documentation is the responsibility of the interior designer. Since product is tested by the composite piece, even though the disparate parts may already have performed to code, this process can be quite involved. Depending on the scale of a project, the cost of sacrificing product to testing may limit the available options and, ultimately, the design itself. Often included in a new or renovated interior are materials that the client has expressed a desire to reuse. If these materials have served well in their previous capacity and still have good, code-compliant components, they may be refurbished for reapplication.

After the ribbon-cutting opens a compliant facility, whether a business or residence, it is the inhabitants and those responsible for maintenance who can unknowingly diminish or even negate code-compliant details. Ultimately, it is the property owner who must take responsibility for the ongoing safety of a building. This involves fire safety training of all inhabitants whether they be residents, customers, employees, or family members.

Understanding what is involved in fire protection and incorporating safety techniques as standard business practice is good customer service. Often the last to leave the project, interior designers have the opportunity and challenge to educate clients on the care, handling, and ongoing maintenance of newly installed interior finishes, fixtures, and furnishings.

Interior designers pass along to their clients a binder of the written specifications, photos, and testing documents for all furnishings, fixtures, and finishes included in their project. This information serves the dual purpose of confirming that the designer has performed his/her responsibilities within the current codes and invites the end-user to be trained on the importance of preserving that compliance.

Less than half of the interior designers certified by the National Council of Interior Design Qualification (NCIDQ) and meeting all requirements for education and experience are able to provide services directly to clients due to the lack of state registration. Only twenty-four states in the U.S. currently acknowledge the profession of interior design through licensure that identifies “registered interior designers” as “design professionals” along with engineers and architects.

Support of interior design legislation is needed to ensure the application of codes by professional interior designers who, along with engineers and architects, champion the health, safety, and welfare of the public.

Lisa Bonneville, ASID, is principal of Bonneville Design, an interior design firm serving residential, retail, business, and healthcare clients. She is also a professional member of the American Society of Interior Designers (ASID), Certified by NCIDQ, member of the NFPA Technical Committee on Furnishings and Contents representing ASID, and chairperson of the Fundraising Committee for the Massachusetts Interior Design Coalition (MIDC) supporting House Bill #2592 for licensure for interior designers.

flashpoints

fire protection industry news

Sunderland Joins Universityof Maryland

Dr. Peter B. Sunderland has joined the Department of Fire Protection Engineering, University of Maryland, as Assistant Professor. He was previously at the National Center for Microgravity Research at the NASA Glenn Research Center in Cleveland, OH.

Professor Sunderland's degrees are from Cornell University (B.S.), the University of Massachusetts (M.S.), and the University of Michigan (Ph.D.). His research interests are in combustion and fire protection. His specializations include soot formation, microgravity combustion, laminar diffusion flames, oxygen-enhanced combustion, and experimental methods in combustion.

For more information visit
www.eng.umd.edu.

NIST Provides Fire Resistance Data on WTC Floor Systems

Four fire resistance tests conducted on composite concrete-steel trussed floor systems typical of those used in the World Trade Center (WTC) towers showed the test structures were able to withstand standard fire conditions for between one and two hours, according to the National Institute of Standards and Technology (NIST).

The 1968 New York City building code – the code the towers were intended but not required to meet when they were built – required a two-hour fire rating for the floor system.

Shyam Sunder, lead investigator, explains that the tests provide only a means for evaluating the relative fire resistance rating of the floor systems under standard fire conditions and according to accepted test procedures. Sunder cautions, "These tests alone cannot be used to determine the actual performance of the floor systems in the collapse of the towers. However, they are already providing valuable insight into the role that the floors may have played in causing the inward bowing of the perimeter columns minutes before both buildings collapsed."

More information visit
http://wtc.nist.gov.

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The SFPE Corporate 100 Program was founded in 1976 to strengthen the relationship between industry and the fire protection engineering community. Membership in the program recognizes those who support the objectives of SFPE and have a genuine concern for the safety of life and property from fire.

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Unique Interiors on the *Las Vegas Strip*

By Doug Evans, P.E.

INTRODUCTION

Many of the largest and most unique buildings in the world are located on the Las Vegas Strip. The interiors of these facilities gives one the impression of being somewhere else and/or in a different time.

In Las Vegas, one can travel to Paris, New York, Venice, Egypt, or a tropical island, as well as another solar system, all within a few blocks. It is possible to take a trip back in time to the Wild West, the Roman Empire, or medieval Europe. Fantasy abounds, and to create these fantasies, the interiors of the facilities are transformed to achieve the desired illusion.

The interiors of these facilities contain

artificial trees, large statues, hand-painted canvas murals adhered to the walls and ceilings, as well as giant signs/LED screens, and numerous other types of themed façades. These themed interiors even include faux buildings inside the main facility.

How can the required fire protection aspects be incorporated into these themed facilities and still allow architectural freedom to achieve the design concept? What level of fire protection is reasonable?

This article focuses on the two previous questions to provide guidance in determining what level of protection is reasonable and offers some examples to demonstrate how that level of protection can be achieved. When determining a reasonable level of protection, the first aspect to consider is the hazard that must be mitigated.

CONSIDERATION OF THE POTENTIAL FIRE HAZARD

Looking at the subject from a performance-based viewpoint, the following aspects need to be considered.

- Proximity to fire sprinklers.
- Obstructions to sprinkler discharge.
- Flammability characteristics (ignition temperature, flame spread, heat release rate).
- Type of substrate and method of attachment.
- Physical properties of the decorative item (size, thickness, and product type).
- Properties of topical applications (pigments, varnishes).
- Combustible concealed voids (compartmentation, sprinkler installation, and plenums).
- Fire-retardant applications.
- Applicability of recognized fire tests.
- Whether hazards are temporary or permanent.
- Proximity to, and significance of, ignition sources and adjacent fuel packages.
- Obstructions to occupant evacuation.

APPLICABLE FIRE TESTS

There are many different fire tests that can be used to provide an understanding of the burning characteristics of materials and assemblies. Several of the tests that may be applicable for the features discussed in this article are summarized in the following paragraphs.

Bench-Scale Testing vs. Larger Scale

Factory Mutual Data Sheet 1-4 (Fire Tests)[1] provides general information about fire testing. It indicates that small-scale "bench-type" testing should initially be conducted to determine if adverse behavior of the specific material can be predicted under actual fire conditions.

This Data Sheet also indicates that small-scale testing may not be representative of the respective hazard. Failure to achieve ignition in small-scale tests is not substantial proof of noncombustibility. Large-scale testing may be necessary to determine the actual fire characteristics of a material. Data Sheet 1-4 states that "many materials incapable of achieving self-supporting fire in bench test configurations prove to be very combustible when subjected to larger-scale testing."

Most fire testing references indicate that testing should be performed in accordance with the expected use of the material being tested. Potential ignition sources must also be considered.

UL 94 Vertical and Horizontal Burning, and NFPA 701 Large- and Small-Scale Versions

These types of tests are classic bench-scale test methods that use a Bunsen burner type of ignition source. Except for UL 94 HB, the sample is typically vertical, and the burner is exposed to the lower portion of the sample. Visual observation of flame spread, char rate, and flaming droplets are evaluated. Typically, the burner exposes the sample for very short periods of time.

The results from these tests are only applicable to very small, transient exposure ignition conditions.

UL 1975

In the late 1980s, The Society of Plastics Industry, Inc., and Underwriters Laboratories (UL) developed testing criteria for foam plastics intended for use in exhibit booths, on film production stages, and for decorative objects.[2] Decorative objects include such objects as mannequins, murals, and signs. The amount of exposed foam plastic is dependent on the proposed use and should be tested at the same thickness and density as the expected application. The size of the expected application should be limited to the size intended by the test. Larger applications should be tested in accordance with a larger-scale test.

Foam plastics in exhibit booths and film production are allowed to have a maximum heat-release rate of 100 kilowatts. Decorative objects are limited to 150 kilowatts. Due to the three-quarter pound (0.34 kg) wood crib used as an ignition source, with an approximate peak heat release rate of 18 kW, these tests may be considered small-scale.

The Steiner Tunnel Test

This test is known by several designations, including ASTM E-84, NFPA 255, and UL 723. As described in the *NFPA Fire Protection Handbook*,[3] this test was originally developed at Underwriters Laboratories in the 1920s, and the current physical design was completed in 1948.

This test was developed as a basis to compare the surface-burning characteristics of materials that form the exposed interior finishes of walls and ceilings in a building. Reinforced-cement board is used to establish the zero value, with red oak flooring being assigned a rating of 100. All other tested materials are compared with these two values. The peak heat release rate of the gas burners used as the ignition source is approximately 88 kW.

The flame-spread index is a numerical rating applied to tested materials. It is a calculated value based on the relationship between the distance the flame front extends within the test chamber and the respective time it took to reach that distance. A material with a Class A flame-spread rating has been tested with a flame-spread index of 25 or less. Materials receiving a flame-spread index greater than 25 and up to 75 are assigned a Class B flame-spread rating. Class C materials have a flame-spread index greater than 75 and up to 200. For all classes, the smoke-developed index is limited to a maximum of 450.

One of the most important concepts to be aware of when using the Steiner Tunnel test method is that the burning characteristics of thin combustible materials can be affected by the properties of their substrate. The lid of the furnace constitutes the substrate for thin materials tested in the tunnel. This lid is a noncombustible refractory liner. As such, results obtained from this test method may be quite misleading when no substrate, or a combustible substrate, is expected for the proposed installation. In addition, the ASTM E-84 test standard specifies that the material be tested in the manner in which it is to be used. Therefore, one often-misunderstood requirement is that this test standard expects a substrate to be included when thin combustible materials tested in this manner are installed within a building.

Since its inception, ASTM E-84 has been used to evaluate all interior finish materials. Over the years, it has been recognized that the results of the test method may not be indicative of real-life fire performance. For example, the *NFPA 101 Handbook*[4] discusses tests conducted at the Fire Research Laboratory of the University of California at Berkeley and sponsored by the American Textile Manufacturers' Institute in late 1985. This testing demonstrated that flame-spread measurements alone might not reliably predict the fire behavior of textile wall and ceiling coverings.

Room-Corner Tests

Over the last 30 years, various room-corner fire tests have been used and standardized. One example is the 30-lb (14 kg) wood crib room-corner test (UL-1715) used in many U.S. codes. Other examples include NFPA 265, which was developed specifically to address the flammability of textile wall coverings, and NFPA 286, which was developed to address interior wall and ceiling finish materials.

These NFPA tests were developed to provide additional engineering data such as heat release rate and smoke production as well as providing a visual observation of the extent of burning. These tests use a gas-fired burner placed in a corner of the room with a heat output that replicates the fire growth of the 30-lb (14 kg) wood crib exposure. The burner produces a 40 kW heat output for the first five minutes to simulate a small fuel package, such as a wastebasket. For the following 10 minutes of the 15-minute test, the heat output is increased to 150 kW (or 160 kW, depending on the test) to simulate a larger fuel package, such as a chair. One of the failure criteria is if flashover occurs. See the article in this issue on page 16 for additional information.

These tests provide a more appropriate evaluation with respect to material orientation, its actual installation, and a moderate fire exposure condition. For certain applications, newer versions of codes and standards allow this test as a substitute for ASTM E-84.

Other full-scale fire tests such as large open corner tests (FM 4880 or UL 1040) or nonstandard full-scale fire tests that replicate end-use conditions are also used to provide a more accurate measure of fire performance of wall and ceiling materials.

ORGANIZING THE APPROACH

There are many ways to organize fire protection approaches for unique interiors. One way is to break the features into similar concepts that are already addressed in codes and standards. This approach is outlined in Clark County's *Guidelines for Unique Interiors*.[5]

These guidelines consider of the following unique interior design elements:

- Trim
- Wall Applications
- Ceiling Applications
- Artificial Plants and Statues
- Decorative Structures within Buildings

Trim Items

By its very nature, trim is limited in size and quantity. Features that can be classified as trim typically do not constitute sufficient fire hazard to be a concern. When trim exceeds reasonable limitations, a greater level of protection becomes necessary. The challenge is determining what constitutes "reasonable" limitations?

Trim can include baseboards, chair rails, crown mouldings, door/window frames, and handrails. The length of these trim items is not limited, but Clark County typically limits the height/width to six inches (150 mm). Beyond this, these trim items are considered wall/ceiling finish.

Some codes and standards allow a small percentage of the walls and ceilings to have decorative combustible features that are considered trim. As such, these items are less regulated than if they were classified as building materials. To allow decorative combustible features up to the percentage of the wall or ceiling area specified by code has been taken into account in the Clark County guidelines.

Upon a cursory review of these guidelines, they may appear more conservative than the allowable percentage limitations. Consider a 100,000 sq. ft. (9,000 m^2) casino with the entire allowable percentage installed in one location. As such, the Clark County guidelines take a somewhat different approach than the allowable percentage option by limiting the size of each item and requiring sufficient separation between adjacent items to consider each such item a separate fuel package.

Decorative Wall Applications

Wall-type applications can include murals, tapestries, pictures, signs, or other features that are affixed to or suspended from facility walls. Draperies and other decorative aspects installed in a vertical plane may also be included.

One way to think about wall-type applications is to consider when a picture becomes a wall. A picture or sign can generally be hung on a wall without concern of a fire hazard. As the picture or sign gets larger, the potential hazard increases. At a point, the hazard may even overwhelm the building's fire protection systems.

Paintings hung on walls are typically considered decorative materials. If the painting is removed from its frame and adhered to gypsum wallboard with a noncombustible adhesive, its potential to burn is reduced, since thin materials tend to take on the burning characteristics of the substrate to which they are adhered. Eliminating one surface of a thin material will typically (and sometimes significantly) reduce that material's ability to exhibit significant flame spread. Additional considerations are the material's proximity to ignition sources and automatic fire sprinkler system effectiveness. For example, the higher up a wall a mural is located, the farther it should be from most significant ignition sources and the closer it will be to sprinklers.

An additional constraint is the size of a mural. When exposed to fire, large murals may delaminate, and burning scraps of material may fall down to ignite one or more fires that exceed the intent of the sprinkler design and overwhelm the sprinkler system.

On the Strip, there are several hand-painted murals adhered to facility walls. Many of these have been tested in accordance with ASTM E-84 to meet the required limitations. Smaller murals are deemed "pictures," and E-84 testing is not required.

One hand-painted mural adhered to a facility wall is 130 ft. (40 m) long and 30 ft. (9 m) high. In this instance, flame-spread and smoke-developed ratings were determined using ASTM E84 and found to slightly exceed the allowable limit. An engineered analysis was prepared to determine if an unreasonable hazard existed. Some of the mitigating aspects included:

- The mural was at the upper portion of a high bay space, which placed it near ceiling sprinklers.
- The height of the mural above the floor reduced exposure to ignition sources.
- The openness of the respective facility allowed the mural to be seen by occupants throughout most portions of the space.
- Exits are located such that occupants need not evacuate beneath the mural.

In a different facility, themed wall features were constructed off site, trucked to the building, and hung on the facility walls. The fabricator was of the opinion that these features were "pictures" and that ASTM E-84 testing was not necessary. After some discussion, ASTM E-84 testing was conducted, and the results were found to be within acceptable limitations. Combustible concealed voids created by this application were eliminated to reduce the potential of fire spread within the cavities.

Plastic windows, large signs, and extremely large rear-projection/LED televisions may also be considered wall-type applications. In the themed rotunda portion of Caesar's Forum Mall, the designers proposed several plastic rear-projection screens approximately 30 ft. (9 m) long and 15 ft. (4.5 m) high (see Figure 1). After discussing the burning characteristics of the plastic screens and building fire protection systems, the designers opted to make the screens out of glass.

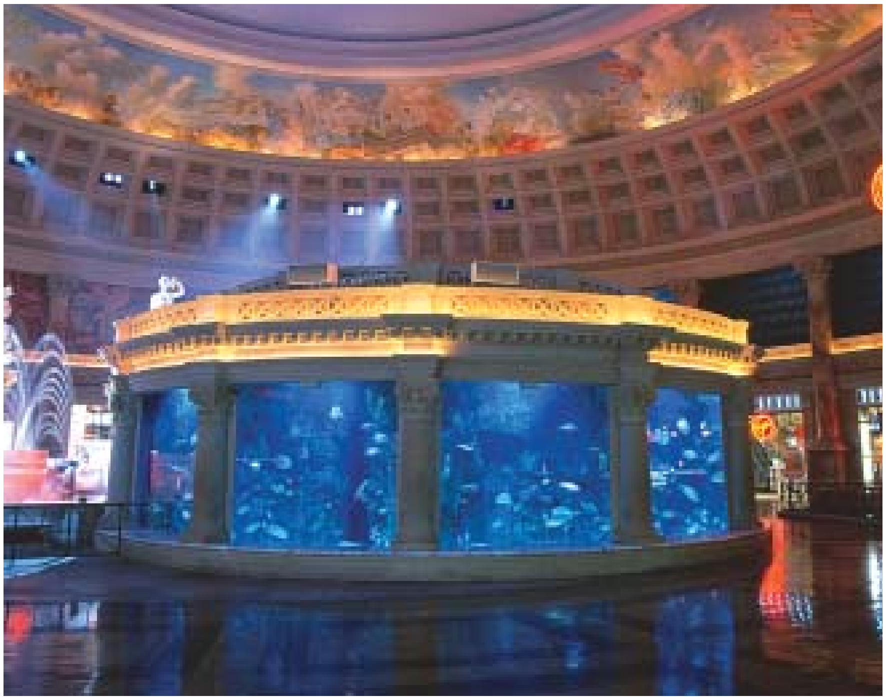
Figure 1. Themed rotunda

In another facility, a manufacturer proposed installing a plastic LED sign 75 ft. (23 m) long and 15 ft. (4.5 m) high with a 6-inch (150mm) hollow interior. This type of application creates a combustible concealed void in which fire can spread unchecked, even if ceiling sprinklers are functioning properly. If sprinklers were installed following the sprinkler installation criteria in NFPA 13, there would be the potential for 5 sprinklers flowing water simultaneously. If sprinklers on both sides of it activate, that's 10 sprinklers. Depending on how the sign is situated relative to ceiling sprinklers, one on each end might even activate. Worst case, there could be 10 to 12 sprinklers flowing water simultaneously. This application approaches the design area of the sprinkler system and certainly constitutes an unacceptable hazard. After discussing the proposal and the potential fire concerns with the manufacturer, this plastic sign was not installed.

When draperies are tested to determine their resistance to ignition, it is typically in accordance with NFPA 701. A primary concern is defining a reasonable size for draperies. Some facilities use draperies to subdivide large spaces. For example, when an arena is only partially filled with people, unused seats are frequently curtained off to create a more intimate feeling. These draperies may contain several hundred square yards (square meters) of material. This arrangement may actually constitute a larger fire and potentially more hazardous condition than is reasonable. Does it seem reasonable that these materials, tested in accordance with NFPA 701, provide an adequate level of protection? What test is reasonable for these applications?

Decorative Ceilings

Ceiling-type applications can include umbrellas, awnings, canopies, nonoccupiable/decorative balconies, interior eaves/projections, lattice ceilings, and roofs of interior structures. This includes all horizontal installations of any material that can cause obstruction to automatic sprinklers and/or delay activation of the sprinklers.

Table umbrellas are frequently about 5 ft. (1.5 m) in diameter. Even though these umbrellas are slightly more than the 4-ft. (1.2 m) limitation to obstruction from sprinkler discharge allowed by NFPA 13, they may not be considered an unreasonable hazard. When decorative ceilings are larger than this, they may create an unacceptable hazard.

There are several unique ceiling-type applications on the Las Vegas Strip. A few such ceilings are fabrics or thin plastics. Thin combustible materials create various challenges. The primary challenge is the potential for adversely affecting sprinkler operation. NFPA 13 requires sprinklers to be installed in the plane of the membrane and at the deck above (within combustible concealed voids).

A concern with this type of arrangement is which set of sprinklers will activate first. If the fire originates between sprinklers, the heat plume may breach the thin membrane, causing sprinklers above to activate first. These sprinklers can be expected to prewet the mem-

Figure 2. Hand-painted mural.

brane below and the piping/sprinklers that penetrate the membrane. Since water from the sprinklers above the membrane may not be able to get to the seat of the fire and sprinklers that penetrate the membrane can be expected to be wet, the fire may spread below. Even if lower-level sprinklers activate, these thin membranes may drape down and restrict proper water distribution. ICBO ES AC 171,[6] using a modified version of the room-corner test, was intended to determine if thin combustible ceilings will create an unreasonable hazard and adversely affect sprinklers. Due to the deck height (9-ft. [2.7 m]) relative to ceiling membrane height (8-ft. [2.4 m]), even this test may provide misleading results when applied to differing geometries.

The thin combustible ceiling applications that have been allowed on the Strip use an engineered approach. Since it is impossible to determine which sprinklers will activate first, or how many, the sprinkler system is designed to flow all sprinklers in the plane of the ceiling, as well as above these ceilings simultaneously. Occupant evacuation is an integral part of the analysis. Due to these constraints, these applications are limited in size, frequency, and their location with respect to exits.

One other ceiling-type application on the Strip includes a hand-painted mural that is 100-ft. (30 m) in diameter (see Figure 2). The burning characteristics of this mural are similar to the mural described previously in the decorative wall applications portion of this article. Part of the mitigating aspects included the height of the mural above the floor and the respective separation from ignition sources.

Other approaches can frequently be used to achieve the design concept. If an interior awning is desired, sandwiching sheet metal between two layers of fabric may meet the design goals. This will reduce the potential for ignition of the fabric, as well as allow sprinklers under the awning to activate properly.

The Las Vegas Strip is also home to one fairly common tropical themed restaurant. The design concept includes walls and ceilings covered with artificial plants. The facility in which this restaurant is located contains a high bay space, and to create a more intimate feeling, the designers wanted drop ceilings made out of these artificial plants. To help ensure proper sprinkler activation, inverted noncombustible “boxes,” using the panelized construction requirements from NFPA 13 for guidance, were suspended from the deck above and then covered with the artificial plants. Sprinklers were installed in the boxes to protect the space below.

Artificial Plants and Statues

This category can include not only artificial plants and statues, but preserved plants, mannequins, models, and small, nonoccupiable decorative structures. Most of these features will be considered fuel loading within the building.

Anyone can go to their local retail store, purchase a 6-ft. (2 m) tall artificial plant and bring it into a building without creating a hazardous condition. When a plant or mannequin becomes 40-ft. (12 m) tall and may include silk or plastic leaves creating a 30-ft. (9 m) diameter, combustible obstruction to sprinkler discharge, the hazard may have increased to an unacceptable level. In addition to considering the fire-protection aspects, these large structures might fall on occupants in the event of a fire. So, not only the fire protection aspects are of a concern, but the structural aspects may also require increased consideration.

The Las Vegas Strip contains numerous statues and artificial trees that are large enough to warrant increased protection. In most cases, they are constructed of materials acceptable for the base building. This means that the structural aspects are minimally noncombustible and, at times, may even be protected from fire. Combustible voids are either eliminated or mitigated. The exteriors of these features are frequently noncombustible. If it is necessary to fabricate the exterior out of combustible materials, they are typically required to meet the ASTM E-84 criteria required for the respective facility.

The leaves of artificial trees constitute thin combustible materials. A 30-ft. (9.1 m) diameter canopy of these leaves creates a challenge for the automatic sprinklers. As such, the sprinkler design density is frequently increased to compensate.

One such feature is a model of a well-known starship (see Figure 3). This model is constructed out of fire-retardant fiberglass-reinforced polymers (FRP). It is approximately 30-ft. (9.1 m) in diameter and creates a 5-ft. (1.5 m) deep combustible void. The architectural arrangement placed this model in a rotunda. As such, sidewall sprinklers were installed around the perimeter to protect the model, as well as the space below. Installing automatic sprinklers inside mitigated the combustible void. The FRP also met the required ASTM E-84 flame-spread and smoke-developed ratings, as well as other applicable requirements to qualify it as a ceiling.

Decorative Structures within Buildings

One example of buildings within buildings may be a small gazebo in a large room that acts as a bar where there may be one or two employees serving cocktails. Glasses may be hung from wooden slats above the bar. A wooden lattice may create an architectural vision ceiling. Generally, this would be considered part of the fuel load within the room.

As the gazebo becomes larger or the room becomes smaller, the gazebo becomes the room. At this point, the gazebo must be constructed as required for the base building.

However, it is difficult to establish the cutoff between these two cases. Here again, if decorative structures are broken into components, concepts can be used that are already addressed in codes and standards. This can include:

- Interior wall/ceiling finishes (as discussed previously in this article)
- Interior façade eave overhangs, decorative ceilings/roofs, and nonoccupiable balconies
- Nonbearing partitions
- Columns and bearing walls
- Mezzanines and occupiable floors/balconies


Figure 3. Starship model

Decorative Ceilings/Roofs

Code requirements for protection of roofs may also be more restrictive than is necessary for interior structures. A roof is considered the upper-most portion of a structure. It is intended to act as a weatherproof membrane and also provide some structural stability. The roofs of interior decorative structures are intended as architectural features and do not fulfill the same role as an exterior roof. Roofs of interior decorative structures can be nothing more than ceilings. As such, the Decorative Ceilings portion of this article can be used for guidance. If these “roofs” provide some structural stability or are expected to support sufficient loads, an increased level of protection exceeding that allowed for ceilings is prudent.

Nonbearing Partitions

Bearing walls constructed of metal or wood studs support more than 100 pounds per lineal foot (0.0445 KN per meter) of superimposed load. If constructed of masonry or concrete, bearing walls support more than 200 pounds per lineal foot (0.089 KN per meter) of superimposed load. Walls supporting less than these amounts are considered nonbearing. Codes and standards typically require bearing walls to have a higher level of fire resistance than nonbearing walls.

Certainly, any supporting element should be protected to at least the level of that which it supports (such as walls supporting a floor or roof).

Columns and Bearing Walls

The structural frame includes columns, girders, beams, trusses, and spandrels having direct connections to the columns and all other members that are essential to the stability of the building as a whole.

Smaller decorative structures within buildings may not be essential to the stability of the base building. The structural frame may not be subjected to the same stresses, such as wind loads, as is the primary framework of the main structure. Therefore, the level of protection may not need to be as restrictive as required for the base building. As the decorative structure increases in size, the level of passive protection will need to be the same as required for the base building.

There are numerous decorative structures inside the major facilities on the Las Vegas Strip, some of which are even high-rise buildings in and of themselves. Many define specific uses, such as retail sales or restaurants. They invariably provide some of the theme inside the base building.

One such decorative structure even looks like a horse. This is the three-story Trojan Horse that greets patrons at the FAO Schwarz Toy Store inside the Caesar’s Forum Mall (Figure 4). The legs are actually fire-rated columns. Since it is possible to walk inside the belly and look down on the main entrance, the floor is a fire-rated slab. The walls, which look like the sides of the horse, meet the requirements for interior nonbearing partitions. Materials that clad the “walls” to give the appearance of a wooden horse were constructed as required for interior wall finish. Since the head bobs up and down, it needed to be light. As such, it is constructed of fire-retardant fiberglass-reinforced polymers and contains one sprinkler inside to provide fire protection. The tail is braided rope and was determined to not be any more of a hazard than a drapery or similar fuel package.

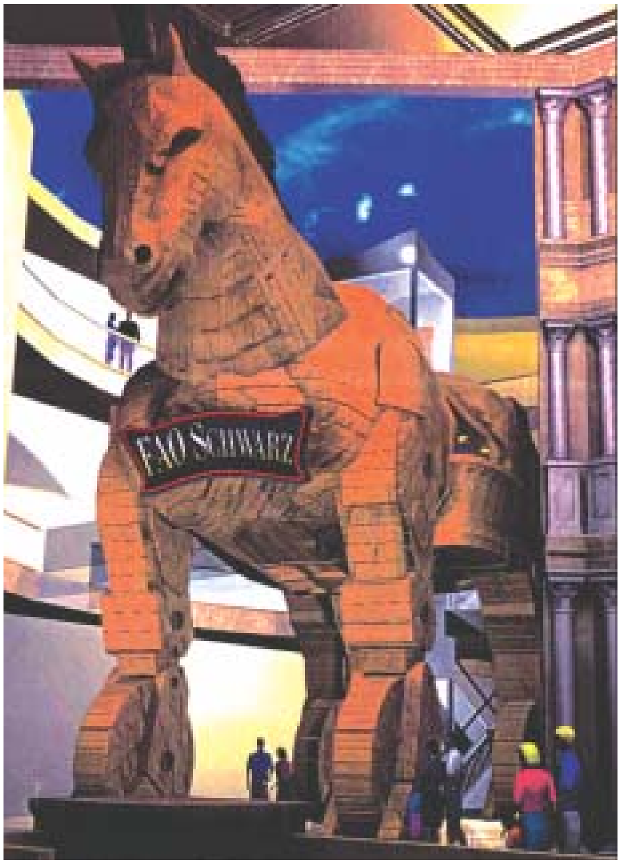

Figure 4. FAO Schwarz Trojan Horse

In another facility, a foam plastic pirate boat was installed. This boat sits above a bar and is approximately 30-ft. (9.1 m) long, 8-ft. (2.4 m) high, and 7.5-ft (2.3 m) wide. Wooden masts extend beyond these dimensions. This is certainly a greater quantity of foam plastics than intended by the UL 1975 fire test described earlier in this article. The interior constituted a combustible void. As part of the mitigating aspects, both the interior and exterior of the feature were fully encapsulated with noncombustible coatings.

Floors/Mezzanines

Mezzanines are intermediate floor levels that do not exceed one-third of the room in which they are a part. Some codes and standards allow the floors of mezzanines to be less fire-resistive than other floors. As such, it may be reasonable to consider multiple-level decorative structures in accordance with these relaxed guidelines. ▲

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Fire Testing *of* INTERIOR FINISH

By Marcelo M. Hirschler, Ph.D.

INTRODUCTION

"Interior Finish" is defined in U.S. codes in a similar manner. The National Fire Protection Association defines "interior finish" as "the exposed surfaces of walls, ceilings, and floors within buildings,"[1] with the explanation that "interior finish is not intended to apply to surfaces within spaces, such as those that are concealed or inaccessible. Furnishings that, in some cases, might be secured in place for functional reasons should not be considered as interior finish." NFPA also considers "interior ceiling finish" as "the interior finish of ceilings," and "interior wall finish" as "the interior finish of columns, fixed or movable walls, and fixed or movable partitions" and "interior floor finish" as "the interior finish of floors, ramps, stair treads and risers, and other walking surfaces."

The International Code Council states that "interior finish includes interior wall and ceiling finish and interior floor finish," that "interior wall and ceiling finish" is "the exposed interior surfaces of buildings including, but not limited to: fixed or movable walls and partitions; columns; ceilings; and interior wainscotting, paneling, or other finish applied structurally or for decoration, acoustical correction, surface insulation, structural fire resistance, or similar purposes, but not including trim," and that "interior floor finish" is "the exposed floor surfaces of buildings including coverings applied over a finished floor or stair, including risers."[2] Thus, when dealing with testing of interior finish, a distinction needs to be drawn between walls (and ceilings) and floors.

The fire performance of interior wall and ceiling finish is critical to the development of a fire: interior finish offers fuel contribution and surfaces through which a fire can spread and transport heat and smoke to other parts of the compartment, or even to other compartments. Therefore, the fire performance of such materials needs to be controlled.

STEINER TUNNEL TEST

The Steiner tunnel fire test method for surface flame spread and smoke development remains the traditional test used to assess fire performance of interior finish materials. Developed by Al Steiner for testing building materials, such as wood or gypsum board, at Underwriters Laboratories in 1944 (Figure 1), the Steiner tunnel test has been standardized by the major North American standards writing organizations (ASTM E-84, NFPA 255, UL 723, ULC S102) and widely adopted by every North American building and fire code.

In the test, a specimen (7.3 m x 0.56 m, normally up to 0.15 m thick), either in one unbroken length or in separate sections joined end to end, is mounted face downwards so as to form the roof of a horizontal tunnel 305 mm high. The fire source, two gas burners, ignites the sample from below with an 89 kW intensity (Figure 2), and the combustion products are carried away by a controlled linear air velocity of 73 m/min (or, exactly, 240 ft/min). The normal output is a flame-spread index (FSI) and a smoke-developed index (SDI). Flame spread is assessed visually by the progression of the flame front, while measurements of optical smoke density at the tunnel outlet determine the smoke obscuration. This information is used to plot time-based graphs of flame-spread distance and of optical density. FSI and SDI are then calculated based on the ratio between the areas under the curves for the material being tested and those for a cementitious board (assigned FSI and SDI values of 0) and for red oak flooring (assigned FSI and SDI values of 100).

Figure 1. Photograph of Steiner Tunnel

Figure 2. Flame in Steiner Tunnel Test

The building, fire, and life safety codes (*IBC, IFC, NFPA 5000, NFPA 101*, and *NFPA 1/UFC*) all contain requirements that limit interior wall and ceiling finish to Class A (FSI ≤ 25; SDI ≤ 450), Class B (25 ≤ FSI ≤ 75; SDI ≤ 450), or Class C (75 ≤ FSI ≤ 200; SDI ≤ 450). A major flaw in the Steiner test appears in the description of the test method above and the results obtained from this fire test: the Steiner tunnel test does not provide results in engineering units. Consequently, the test results cannot be used for a fire hazard analysis or a fire risk analysis.

This test continued to be popular when plastics started to be used in construction and in spite of the fact that the test is not always appropriate for every material. Samples that cannot be retained in place above the tunnel floor or which melt and continue burning on the tunnel floor (typical behavior for most thermoplastics) are still being tested with this equipment even though the results are not representative of the use of the material in realistic situations.[3] The same can also be said about thin materials, which often give low FSI values mainly due to insufficient material in the test method to permit flame spread to be assessed properly. An understanding of some of these limitations has caused the codes to consider alternatives, either as replacements for the Steiner tunnel or as additional options (see section on heat release).

FLOOR FINISH TEST METHODS

Different challenges face interior floor finish than other interior finish because heat and smoke rise in a fire. Thus, floor finish is involved either as the initial material ignited in a fire or as an additional fuel once a fire has become uncontrolled. Consequently, fire safety requirements typically need to ensure that interior floor finish is relatively difficult to ignite and is not capable of slowly spreading flame from the compartment of fire origin to a different one.

The Steiner tunnel cannot assess ignitability, and its fuel source is not appropriate to assess slow flame spread. Experience has shown that many flooring materials (traditional floor finishes such as wood flooring or resilient materials) will not ignite unless exposed to an ignition source of well over > 1 kW/m^2, but that some carpet-like or loose-fill materials may ignite at such low heat fluxes. A study of precision of the flooring radiant panel test method found carpets with critical radiant heat fluxes well under 2 kW/m^2.[4]

Therefore, all carpets and rugs sold in they United States[5] must meet the "methenamine pill" test (ASTM D 2859), which ensures that flame spread will be minimal.

Most codes also regulate interior floor finish (in occupancies where fire risk needs to be especially minimized) to be tested with the flooring radiant panel (ASTM E 648, NFPA 253, Figure 3) and require a "critical radiant flux" for ignition in excess of 4.5 kW/m^2 (Class I) or 2.2 kW/m^2 (Class II). In the flooring radiant panel, the floor finish (such as a carpet) is exposed to an incident heat flux from an angled gas-fired radiant panel, with a maximum heat flux of approximately 11 kW/m^2 at the farthest end from the igniter. The test method assesses the critical incident flux (which is measured by comparing the distance between the igniter and the point where flame propagation stops to a calibration curve) required for continued flame propagation.

This approach (even if it is based on old-fashioned tests) is quite suitable for interior floor finish. Some applications, typically in the transportation vehicle arena, also require flooring materials to meet one of a variety of smoke obscuration requirements, often based on a static smoke chamber box, either with a traditional radiant heater (ASTM E 662) or with a conical heater (ISO 5659-2, IMO Fire Test Procedures Code part 2, also known as ASTM E 1995 and NFPA 270).

Figure 3: Flooring Radiant Panel Test Apparatus (ASTM E 648)

OTHER TEST METHODS

Of course, the key question to ask in any fire is "how big is the fire?", and the answer lies in the rate of heat release.[6, 7, 8, 9, 10, 11] A burning product will spread a fire to nearby products only if it gives off enough heat to ignite them. Moreover, the heat has to be released fast enough not to be dissipated or lost while traveling through the cold air surrounding any product that is not on fire. Therefore, heat-release rate dominates fire hazard, and it has been shown to be much more important than ease of ignition, smoke toxicity, or flame spread in controlling the time available for potential victims of a fire to escape.

The above concepts are now applied to fire testing of interior (wall and ceiling) finish, and all U.S. codes use a room-corner test for the purpose. The use of the room-corner test can be an alternative to the Steiner tunnel test (for most interior finish materials) or

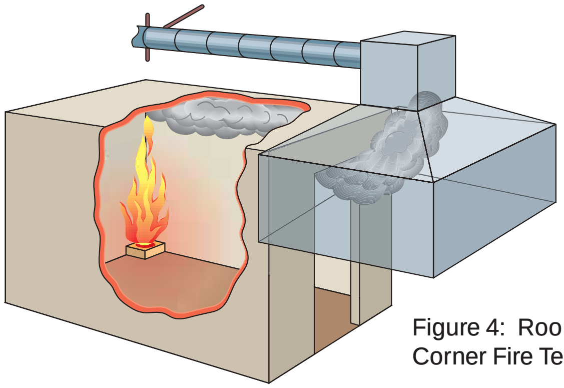

Figure 4: Room-Corner Fire Test

the actual requirement (for foam plastic insulation and textile wall coverings). Thus, the building, fire, and life safety codes allow most interior wall and ceiling finish materials to be tested using the NFPA 286 room-corner test (Figure 4) instead of the Steiner tunnel test, and the test results must then show that the test specimen does not cause flashover during the assessment and does not emit a total amount of smoke exceeding 1,000 m^2. The total amount of smoke released is a measure of smoke obscuration (or smoke opacity) calculated as the integral, over time, of the smoke-release rate across the surface of the duct used for the measurement. Thus, the smoke release rate is measured in units of surface area over time and the total smoke released in units of surface area (such as m^2).

Special rules apply to some materials or products, as follows:

- Textile wall and ceiling covering materials are required to meet a Class A flame-spread index and smoke-developed index (using the Steiner tunnel fire test), and be used in a sprinklered environment or have passed a specific room-corner test for textile wall coverings (NFPA 265, a less severe test and one where there are no smoke obscuration requirements), which requires that flashover not occur.
- Expanded vinyl wall coverings can be treated like textile wall coverings (see above) or like most other interior finish (use the Steiner tunnel or NFPA 286).
- Cellular or foamed plastic materials must always meet a Class B flame-spread index (using the Steiner tunnel test). They can be used as interior trim if the density of the material is high enough (> 320 kg/m^3), and when used in that way, the amount of cellular foam is limited to 10% of the wall or ceiling. Alternatively, cellular or foamed plastic materials must meet the standard smoke obscuration requirement (smoke-developed index of <450, using the Steiner tunnel test) and must either be covered by a thermal barrier or meet a large-scale fire test that fully represents the fire hazard in the scenario in question. One of such tests is the NFPA 286 room-corner test.

ROOM-CORNER TEST

In the NFPA 286 room-corner test, three walls and the ceiling (or ceiling only, for interior ceiling finish) of a 2.4 m x 3.7 m x 2.4 m high room, with a standard doorway, are lined with the material to be tested. The ignition source is a gas burner placed in one corner (on the wall furthest from the doorway) flush against both walls that generates 40 kW for a 5-minute period, followed by 160 kW, for a further 10-minute period.

Heat release (based on the principle of oxygen consumption calorimetry) and smoke release are measured in the exhaust duct, and temperatures and heat fluxes are measured in the room.

The severity of the ignition source was designed to ensure that the gas burner flame alone reaches the ceiling, without contribution from the test material (Figure 5). Even though the test measures heat release, the codes simply require assessment of whether flashover occurs during the test, so much of the information collected during the test is not used.

Figure 5. Flame in Room-Corner Test

Research was conducted to look into issues associated with room-corner testing.[12, 13, 14] As a result, two additional important criteria required by the codes are that the flame spread does not reach any of the extremities of the test sample and that the total smoke release cannot exceed 1,000 m^2 over the entire 15-minute test period.

If all criteria are met, the material is suitable for use in all applications where the codes require a material to be tested by the Steiner tunnel and where Class A, B, or C requirements exist. In practice, it is rare for a material to spread flame to the extremities of the test sample and still not cause flashover, since that would mean that the flame would reach the edge of the door and stop without exiting the doorway (one of the criteria for flashover). This means that any material that does not cause flashover and releases < 1,000 m^2 of smoke is considered equivalent to a Class A material. In fact, it is likely that materials with very high heat-release rates (but not quite enough for flashover) should probably be classified separately from materials that have low peak rates of heat release rate.

NFPA 265 is a somewhat less severe variation of NFPA 286, which is applied exclusively to textile wall coverings (and expanded vinyl wall coverings). In NFPA 265 and NFPA 286, identical test rooms and identical gas burners are used. There are three main differences, however, in the ignition sources used for both tests: 1) in NFPA 265, the burner is placed 51 mm away from each of the walls, as opposed to flush against the walls as in NFPA 286 (but it is placed in the same corner as in NFPA 286); 2) in NFPA 265, after the first 5 minutes at 40 kW, the burner intensity is raised to 150 kW, as opposed to 160 kW in NFPA 286; and 3) smoke release measurements using NFPA 265 are not required in the codes. It is likely that, eventually, textile wall coverings will be required to be treated similarly to other interior finish.

ANALYSIS OF TEST METHODS

Now that the actual tests used have been presented, it is important to discuss the validity of the test methods and whether improvements should be put in place. One obvious improvement which would permit a much more logical approach to using fire safety engineering methods would be to apply a test method based on heat release for testing interior floor finish (such as the cone calorimeter, a bench-scale test, e.g., for example, ASTM E 1354, NFPA 271, ISO 5660).

In fact, two ASTM guides and one NFPA guide addressing fire hazard assessment, ASTM E 2280 (for healthcare occupancies), ASTM E 2067 (for rail cars), and NFPA 555 (on potential for flashover), all recommend the use of the cone calorimeter to assess heat and smoke release of interior floor finish, at incident heat fluxes of 25-30 kW/m^2. However, it is true that the combination of the methenamine pill test and the flooring radiant panel test is sufficient to eliminate the vast majority of “bad actors.” Thus, the methods being used are fairly adequate for a prescriptive fire safety approach that does not discriminate against materials. The additional smoke release testing (used mostly in transportation environments) is not of very high value, but it may serve to eliminate some poor performing materials.

There continues to be controversy with regard to smoke release testing of interior wall and ceiling finish. In a field that continues to be dominated by the Steiner tunnel test (despite its well-known inadequacies for testing some materials) the ques-

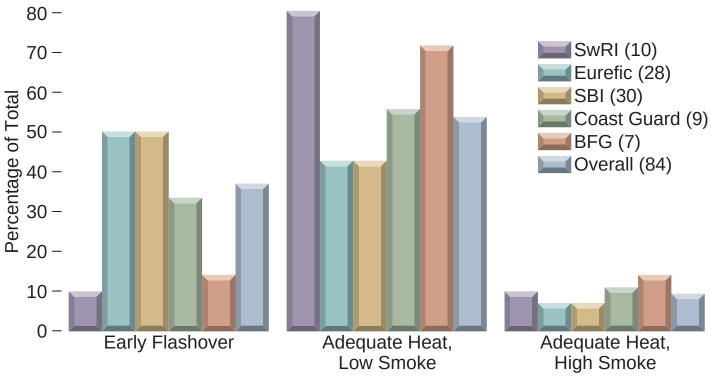

Figure 6. Room Corner Testing, Heat & Smoke Release

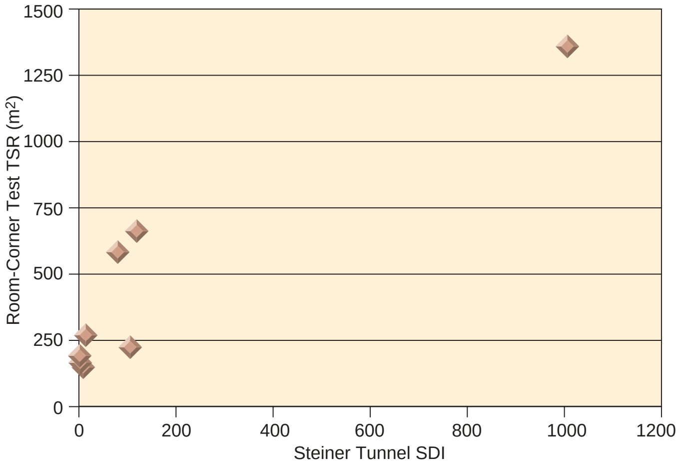

Figure 7. Smoke Release of Interior Finish

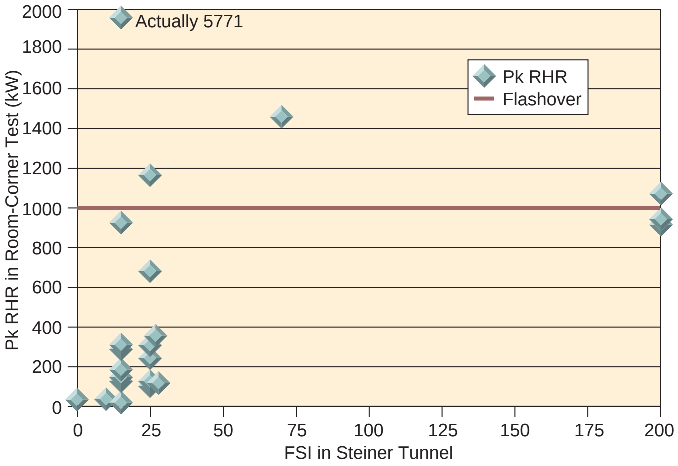

Figure 8. Rate of Heat Release vs Flame Spread

tion arises: Is it necessary to test for smoke release in the room-corner test, or is it enough to just develop low heat release products?

Figure 6[15] shows that of five series of tests conducted in room-corner tests, systematically some 10% of the materials (10 of the 84) give low heat release but unacceptably high smoke release. So the importance of assessing smoke release of interior wall and ceiling finish in a large-scale test is clear. Code writers then saw that both flame spread and smoke release (or heat release and smoke release) must be assessed to adequately regulate the fire performance of interior wall and ceiling finish materials, whatever test method is used.

Thus, a smoke-release criterion needed to be added to fire testing using the room-corner test (such as NFPA 286), for which heat release only used to be measured, while both flame spread and smoke release have always been required in the Steiner tunnel test. The data in Figure 7[12, 13, 14] shows that this problem can be resolved (and has now made its way into codes) by using equivalent criteria in both tests, since materials with very high smoke-developed index (SDI) are also likely to have a very high total smoke release (TSR) in the room-corner test, which is how the 1,000 m^2 pass-fail criterion was developed.

In light of steady research, it becomes clear that for all of its traditional merits, the approach of codes to testing interior wall and ceiling finish is a slightly flawed concept. Clearly the room-corner test is a much more accurate way of assessing fire performance than the Steiner tunnel test. However, the codes allow the NFPA 286 room-corner test results based on the premise that materials that do not cause flashover (or high smoke release) in the room-corner test are known to also have flame spread indices of < 200 and smoke developed indices of less than 450 in the Steiner tunnel test.

These provisions work well to a point but need refinement. The Steiner tunnel test is likely to give falsely favorable results (in fact, this happens often with materials that melt and drip and with materials that are thin films) but it rarely gives falsely unfavorable results (meaning that a high flame-spread index, or FSI, is almost always indicative of a material with mediocre or poor fire performance). The room-corner test results are potentially much more suitable to classification of materials, because the heat release rate history is obtained in the test. However, the fact that the heat release rate history is not used for code classification purposes results in some inconsistencies occurring when comparing results from both tests. Therefore, it would be important to use the heat release rate history in the room-corner test in conjunction with testing whether flashover does or does not occur.

Figure 8 (based on a survey of published data developed for this work) shows the comparative fire performance of 25 materials tested in the Steiner tunnel and in the room-corner, and illustrates the problem:

- 5 materials had an FSI of 200 or less (i.e., Class A, B, or C) in the Steiner tunnel but caused flashover in the room corner test. The Steiner tunnel test classifies them as acceptable and the room-corner test as unacceptable.
- 14 materials had an FSI of 25 or less (i.e., Class A) in the Steiner tunnel and released less than 400 kW in the room-corner test. Both tests classify them as Class A.
- 2 materials had an FSI of > 25 and < 75 (i.e., Class B) in the Steiner tunnel and released less than 400 kW in the room-corner test. The Steiner tunnel test classifies them as Class B and the room-corner test as Class A.
- 2 materials had an FSI of 25 or less (i.e., Class A) in the Steiner tunnel and released more than 400 kW but did not cause flashover in the room corner test. Both tests classify them as Class A.
- 2 materials had an FSI of 200 or less (i.e., Class C) in the Steiner tunnel and almost caused flashover in the room-corner test. The Steiner tunnel test classifies them as Class C and the room-corner test as Class A.

In conclusion, fire testing of interior finish is probably adequate to eliminate the poorest performers (both in terms of heat release, or flame spread, and smoke release). However, in terms of maximizing the usefulness of current research and to accommodate modern building materials, the Steiner tunnel test falls short. In applying a variety of new and specific tests, the full capabilities of the room-corner test, including the actual heat release rates measured, could be incorporated into engineering, and improvements in that area would be welcome. ▲

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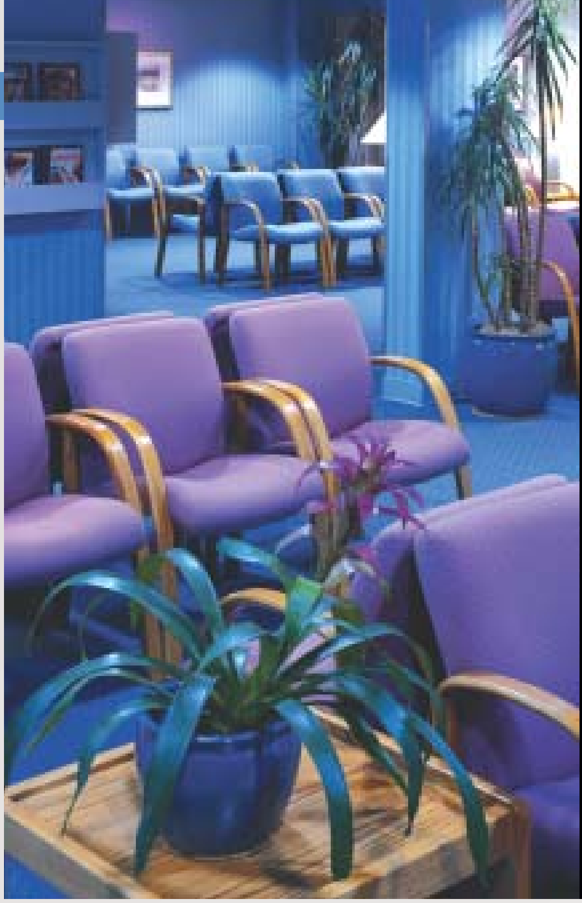

The Role of Interior Finish in Fire Development

By Robert Brady Williamson, Ph.D., P.E., and Frederick W. Mowrer, Ph.D., P.E.

INTRODUCTION

Combustible interior finishes, which include the exposed ceiling, wall, and floor linings in buildings, are large continuous surfaces over which fires can spread.[1] These finishes, along with combustible furnishings and contents, provide the fuels that can permit the development of enclosure fires, in many cases, to flashover conditions. Depending on the flammability characteristics of the interior finishes and the fire scenarios in which they are involved, interior finishes may serve as the primary fuel driving a fire to flashover or as a secondary fuel acting as a "fuse" to spread a fire between primary fuel packages. Once flashover occurs and all exposed combustible surfaces within an enclosure ignite, interior finishes may represent the most significant fuel package contributing to the post-flashover fire because of their large surface areas and total energy content.

Because of their potential to serve as the primary fuel driving an enclosure fire to flashover, the flammability characteristics of interior wall and ceiling finishes have been regulated for more than 50 years. In this paper, the roles of different interior finishes in fire development are addressed. An historical perspective of the significant fires that have shaped the regulation of interior finishes in the United States is presented. The scientific understanding of fire spread over interior finishes has developed significantly over the past 25 years, along with the quantitative methods needed to evaluate the fundamental flammability properties of materials. Theoretical concepts associated with flame spread theory are presented in the following section. These concepts demonstrate that, to a large extent, flame spread on interior finishes can be viewed as a race between the ignition and burnout of fuel surface elements. Finally, a new way of evaluating, and perhaps eventually regulating, the flammability characteristics of combustible interior finishes is presented. This methodology provides a way to move away from the current empirical basis for the regulation of interior finish flammability to a more quantitative scientific basis.

HISTORICAL PERSPECTIVE

As a result of a number of major and widely publicized building fires in the United States during the 1940s, including the Cocoanut Grove fire[2] in Boston, the LaSalle Hotel fire[3] in Chicago, and the Hotel Winecoff fire[4] in Atlanta, the role of interior finish in fire development became more widely recognized in the fire protection engineering and building regulation communities than it had been previously. That these fires occurred in buildings of so-called "fireproof" construction highlighted the contribution of the interior finishes and decorations to these fires.

Following the Cocoanut Grove fire in 1942, but before the LaSalle Hotel and Hotel Winecoff fires in 1946, A. J. Steiner of Underwriters' Laboratories published a test method to classify the hazards of building materials.[5] As noted by Steiner[6] apparently in reference to the Cocoanut Grove fire, "Public concern is aroused periodically when a rapidly spreading fire kills a large number of people or produces an extraordinary property loss. This concern prompted the development of a test method whereby the fire hazards of materials could be measured and classified with reference to the rate of spread of fire, the amount of fuel contributed to the fire, and the production of objectionable smoke while burning." This test method is now widely known as the "tunnel test" because of the duct-like configuration of the fire test chamber or as the "Steiner tunnel test" in honor of its principal developer.

In 1950, ASTME84-50T, *Tentative Method of Fire Hazard Classification of Building Materials*,[7] was first approved by the American Society for Testing and Materials as a tentative standard. This test method was adopted by all the model building codes in the United States and by the *NFPA Building Exits Code* (now the *Life Safety Code*), resulting in widespread regulation of the "flame spread" and "smoke development" of interior wall and ceiling finishes based on tunnel test results. The tunnel test remains the primary fire test method used to regulate the flammability of interior wall and ceiling finishes in the United States more than 50 years later, despite recognition of its technical shortcomings and the development of more realistic fire test methods for interior wall and ceiling finishes.

In 1950, Factory Mutual Laboratories (FM) published a report[8] describing a room fire test method to evaluate the life hazard of interior finishes. In the aftermath of the large life-loss fires of the 1940s identified above, this report noted that, "There is considerable agitation at the present time to write regulations governing the use of interior wall and ceiling finish materials, in the interest of reducing the life hazard in public areas where these materials are used in quantity. Before adequate and equitable regulations can be established, fire conditions constituting a life hazard will, of necessity, need to be defined and materials tested under such conditions of exposure." FM developed a test room approximately 4.2 m (14-ft.) by 6.1 m (20-ft.) by 3.7 m (12-ft.) high. FM experimented with a number of ignition sources consisting of wood cribs weighing from 2.3 kg to 13.6 kg (5 lb to 30 lb) and/or ethyl alcohol weighing from 0.2 kg to 3.4 kg (1 lb to 7.5 lb) placed in a corner of the room.

The conclusion of the FM report was that the ignition source consisting of 7.5 lb of wood and 0.75 lb of alcohol was considered to be "the most suitable exposure in this enclosure for establishing the extent to which interior wall and ceiling finish materials contributed to produce a life hazard. Several factors influenced the selection of this exposure: 1) It was of sufficient intensity to ignite materials causing them to burn and contribute to the rise of temperature within the enclosure. 2) Its location in one corner of the room adjacent to two walls produced a maximum exposure condition to wall and ceiling material. 3) It was the largest test exposure that could be used without producing a life hazard in the test enclosure by the burning of the enclosure itself. 4) This exposure ... produced a temperature of 155°F (68°C) at the breathing level, which was sufficiently below the chosen life hazard temperature of 300°F (150°C) to determine to what extent the wall or ceiling material would contribute a life hazard."

This FM report is significant for a number of reasons. It represents one of the first systematic efforts to evaluate the flammability of interior wall and ceiling finishes in an end-use configuration. It recognizes that fires located in corners represent a realistic worst-case exposure geometry for wall and ceiling linings. It establishes a selection process for ignition sources that challenge the materials being evaluated but do not overwhelm their performance. Unfortunately, the room fire test method developed by FM to evaluate the life hazard of interior finishes never gained the widespread acceptance within the building regulatory community that the tunnel test did.

Through the 1950s, the tunnel test method became more firmly entrenched as the standard for regulating the flammability characteristics of interior finish materials despite the fact that it only had tentative status under ASTM. During this period, the use of plastics in building construction also started to grow tremendously. Both Steiner[9] at UL and Wilson[10] at FM voiced concern with the small-scale laboratory procedures, such as ASTM D635 and D1692, and the terminology, such as "self-extinguishing," "slow-burning," and "nonburning," being used to evaluate and describe the flammability performance of plastic building products.

Wilson noted that these small-scale laboratory tests are "intended solely for comparing the relative flammability of various plastic materials," and that they "are neither designed nor appropriate for the rating of plastic products as building materials." Steiner noted that "the tests which classify plastics as self-extinguishing and slow-burning do not correlate with the Fire Hazard Classification. To illustrate, some time ago a plastic which had been classified as slow-burning was subjected to the tunnel test, and the results were disastrous. The material burned so fiercely and created so much smoke and molten residue that it took days to clean up and repair our furnace. Need for action by a fire protection group is essential to control the fire hazard being created." Steiner went on to say that "the value of results of a test are dependent on their significance as related to their use, based on actual field fire experience."

Steiner was a proponent of small-scale tests as "effective instruments for development and research, as well as tools for inspection," but he also recognized their limitations: "The small-scale tests can be used in the examination of products to determine whether they provide the same properties as other materials tested in the same manner ..., but they do not provide fire protection information on the behavior of the product, or of assemblies employing it, under actual use conditions in buildings." He goes on to say that "the same fire protection engineering considerations must be given to all tests, whether small or large. The results must be representative of actual conditions, the classifications must be realistic and the requirements consistent." It is interesting to note that Steiner[11] viewed the tunnel test as a large-scale test, while others[12] have viewed the tunnel test as a small-scale test.

In 1961, Wilson[13] reviewed a number of test methods then being used to evaluate the surface flammability of materials. Wilson noted that "None of the agencies developing these test methods has reported any relation between their test results and actual fire conditions. ... There has been nothing reported to indicate that four of the test methods (including the tunnel test) have ever been directly compared with any form of actual fire condition." Both Steiner and Wilson seemed to agree that the results of fire tests should be representative of actual conditions to be valid.

Through the 1960s, some of the technical shortcomings associated with the tunnel test began to be recognized more widely when the tunnel test was used to evaluate the flammability characteristics of newly developed foam plastic insulation products that were starting to be used in buildings. Some of these products received low flame-spread ratings in the tunnel test, yet rapidly spread fires when installed in buildings. This anomalous propensity for rapid flame-spread and fire development on exposed foam plastics despite low flame-spread ratings was demonstrated by newly developed open-corner fire tests[14] that more realisti-

Figure 1. Open-corner test of a foam plastic insulation product with a reported flame-spread classification of 25.

cally simulated the dynamics of enclosure fires than the tunnel test did. An example of this anomalous behavior is illustrated in Figure 1, which shows an open-corner fire test of a polyurethane foam insulation product with a low reported flame-spread rating.

As a consequence of the little-known Childress residence fire[15] in which two children died as a result of a fire involving exposed polyurethane foam insulation installed in their home, the Federal Trade Commission (FTC) filed a proposed complaint[16] against 27 respondents, including 25 manufacturers of foam plastic products and 2 trade organizations, the Society of the Plastics Industry (SPI) and the American Society for Testing and Materials (ASTM), claiming that the respondents were knowingly marketing foam plastic insulation products with misleading representations that such products were “nonburning” and “self-extinguishing” on the basis of inadequate test methods, including the tunnel test.

There was a great deal of activity during the year after the FTC proposed complaint was issued, which culminated in the “Complaint and Decision” of November 4, 1974, that included a Consent Decree signed by 24 companies and the SPI[17]. As part of the Consent Decree, the respondents agreed to perform many activities, which ranged from notifying all prior purchasers of foam insulation products of the dangers of the products to sponsoring and conducting research into the proper ways to protect foam plastic insulation products. These activities are summarized in the 1980 Final Report of the Products Research Committee,[18] which was formed to administer a $5 million trust fund established as part of the Consent Decree.

Between the time when the FTC Consent Decree was signed in 1974 and the PRC Final Report was issued in 1980, the use of thermal barriers to separate foam plastic insulation products from occupied spaces in buildings became the standard practice. For example, the 1973 edition of the *Uniform Building Code (UBC)* did not make any reference to foam plastics while the 1976 edition of the *UBC* included a new section (Section 1717) devoted exclusively to foam plastics. This new section generally required foam plastics to be separated from the interior of a building by a thermal barrier, such as 1/2 in. (13 mm) thick gypsum wallboard, having a finish rating of not less than 15 minutes unless specifically approved on the basis of "approved diversified tests," including "fire tests related to actual end-use such as a corner test." The details of a diversified test to be used for evaluating foam plastics were not specified until 1982.

Room fire test methods were used increasingly during the mid- to late-1970s as an alternative to the open-corner fire tests that had been used during the 1960s and early 1970s. In 1975, Underwriters Laboratories reported[19] on a series of flammability studies of interior finishes that included room fire tests. In 1977, ASTM first published ASTM E603, *Standard Guide for Room Fire Experiments*. This document noted that, "There is no standard room fire test at the present time, and this report does not define one. It does set down many of the considerations for such a test: for example, room size and shape, ventilation, specimen description, ignition source, instrumentation, and safety considerations which must be decided upon in the design of a room fire experiment."

In 1979, Williamson and Fisher[20] described efforts then underway at the University of California, Berkeley, to develop a standard room fire test method. They subsequently reported[21] on their efforts to evaluate this room fire test method. They used an enclosure with dimensions of 2.4 m (8-ft.) wide by 3.7 m (12-ft.) long by 2.4 m (8-ft.) high, which was becoming the most typical enclosure size for room fire tests. This work and related work at other fire research laboratories resulted in a proposed ASTM standard room fire test method for wall and ceiling materials and assemblies[22] in 1982, but this proposed standard was never adopted by ASTM.

In 1982, Uniform Building Code Standard No. 17-5, *Room Fire Test Standard for Interior of Foam Plastic Systems*, was first published to "detail a test method to evaluate the burning characteristics of foam plastic assemblies in a standard room configuration" and thus to serve as an approved diversified test for foam plastics under the *UBC*. This standard specified a room 2.4 m (8-ft.) wide by 3.7 m (12-ft.) long by 2.4 m (8-ft.) high with a doorway 0.8 m (2-ft. 6-in.) wide by 2.1 m (7-ft.) high centered in one of the 2.4 m (8-ft.) long walls of the enclosure. The ignition source specified for this test method was a 13.6 kg (30 lb) wood crib located 25 mm (1 in.) from a corner opposite the doorway opening.

During the 1980s, another series of hotel fires occurred that was reminiscent of those in the 1940s, except that these hotel fires involved modern high-rise buildings with interior finish materials that should have met modern regulatory requirements. The first of these hotel fires was the November 1980 fire at the MGM Grand Hotel[23] located along the Las Vegas Strip in Clark County, Nevada. The early development of the MGM Grand fire was on the interior wall and ceiling finishes of a service side station in the deli restaurant on the casino level.[24] Once the fire flashed over the side station, it quickly enveloped the deli restaurant, feeding on the combustible interior finishes and furnishings in the restaurant. The deli restaurant then flashed over, and the fire spread into and along the length of the casino, which was roughly the size of a football field. The fire was confined to the casino level, but 85 people died as a result of this fire, with approximately 68 of the victims located on the upper floors of the high-rise portion of the building above the casino.

Three months after the MGM Grand Hotel fire, the Las Vegas Hilton Hotel[25] suffered a devastating fire that killed 8 people. This fire started in the 8th floor elevator lobby in the east wing of the 30-story building. The walls and ceiling of this elevator lobby, as well as all the other elevator lobbies on floors served by these elevators, were lined with a textile carpet material. The fire in the 8th floor elevator lobby developed to flashover, then spread from the 8th floor to the 28th floor of the building via the exterior windows located in each elevator lobby. The fire did not reach the 29th floor because of an architectural detail that deflected the flame out and away from the lobby windows.

The Las Vegas Hilton Hotel fire and other less-publicized fires involving textile materials motivated the textile industry to sponsor research at the University of California, Berkeley, to evaluate how well the tunnel test predicts the performance of textile wall coverings.[26] As a result of this research project, a room fire test method for textile wall coverings was developed. This room fire test method was adopted as *UBC* Standard 42-2 in 1988 and is also currently designated as NFPA 265, which is referenced by the *Life Safety Code* and the *International Building Code*.

The fire at the DuPont Plaza Hotel[27] in San Juan, Puerto Rico, occurred on December 31, 1986. This fire, which claimed the lives of 99 people located in the hotel's casino, started in a ballroom located across a covered foyer from the casino. The fire in the ballroom developed to flashover conditions on the new furniture being stored in the ballroom as well as on the textile wall material and foam-insulated movable partitions lining the walls of the ballroom. The combustible ceiling in the foyer also contributed to the fire development.

With the exception of the Las Vegas Hilton Hotel fire leading to the development of the room fire test method for textile wall coverings, the hotel fires of the 1980s did not inspire significant changes to interior finish requirements in the building regulations. Instead, these fires motivated the widespread use of automatic sprinkler protection in high-rise hotels and other residential and commercial buildings where sprinkler protection had not traditionally been installed.

The fire at the Station nightclub in West Warwick, Rhode Island, in February 2003 provides the latest extreme example of the role of interior finish in fire development. This fire, which claimed the lives of 100 victims and injured hundreds more, spread very quickly, primarily on the exposed convoluted flexible polyurethane foam material that had been installed on the walls and ceiling of the bandstand in the nightclub. This foam plastic product reportedly was intended for use as a packing material and therefore did not incorporate even a nominal amount of fire retardants. In light of the widespread recognition of the fire hazards associated with exposed foam plastic interior finishes and the regulation of the application of these products since the 1970s, it is difficult to comprehend how this application could have existed in 2003. It should serve as a reminder to fire safety professionals everywhere of the need for continual diligence.

Much of the focus on the Station fire has been on the lack of automatic sprinkler protection in the nightclub rather than on the exposed foam plastic interior finish that ignited so easily and spread the fire so quickly. Recent large-scale experiments conducted at the National Institute of Standards and Technology[28] with a wet-pipe sprinkler system and quick-response sprinklers suggest that the presence of similar automatic sprinkler protection in the Station may have significantly improved the outcome of the fire there. While automatic sprinkler protection is widely recognized to be beneficial for both life safety and property protection, it should not be considered as an acceptable trade-off for unsafe and improper installations of foam plastic materials as interior finishes. Where such installations of exposed foam plastics exist, they should be removed, regardless of the presence of automatic sprinkler protection.

FLAME SPREAD THEORY AND MODELING

Concurrent with the development of room fire test methods that more accurately portray the performance of building materials under actual fire conditions, the scientific understanding of flame spread on solid surfaces has advanced, and models of the flame spread process have been developed. For example, Quintiere[29] has developed a fairly comprehensive yet relatively simple simulation model for flame spread that has been incorporated in the BRANZFIRE zone fire model.[30]

The ultimate objective of research on flame spread is to be able to predict the development of fire under a full range of scenarios based on fundamental material flammability properties obtained from quantitative small-scale tests, such as the Cone Calorimeter,[31] the LIFT apparatus,[32] and the FM Fire Propagation Apparatus.[33] While considerable progress has been made, there is still a need for large-scale testing, both to verify model predictions and to evaluate performance characteristics of some materials and as-

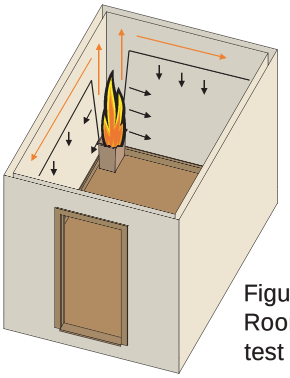

Figure 2. Room-corner fire test geometry.

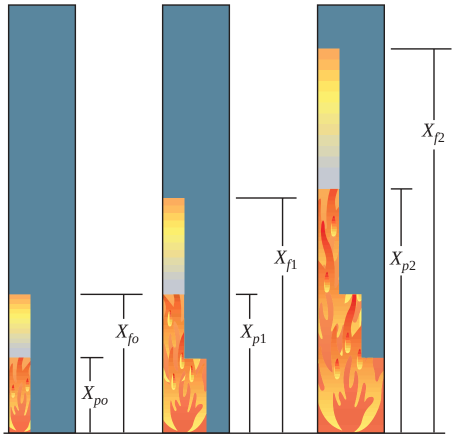

Figure 3. Conceptual illustration of flame spread as a sequence of ignitions.

semblies that cannot yet be modeled accurately, such as melting, dripping, delamination, and warping.

Consider the scenario depicted in Figure 2, which is representative of the scenario used in most room fire tests. The walls and/or ceiling of an enclosure are lined with a combustible interior finish material. A section of the lining material is subjected to an imposed heat flux from an ignition source fire, which is normally selected to represent a typical incidental fire, such as a small trash receptacle fire.[34] Such ignition sources are normally selected to realistically challenge the lining materials but not overwhelm the performance of the lining materials. In room fire tests, such ignition sources are typically located near the corner of two walls because this represents a realistic "worst-case" ignition scenario, as noted in the 1950 FM room fire tests.

The section of lining material directly behind the ignition source will be the first to ignite. The flame on this section then may spread vertically and beneath the ceiling, as indicated by the orange arrows in Figure 2, as well as laterally and downward, as indicated by the black arrows in Figure 2. In general, the upward flame spread and spread beneath a ceiling are known as wind-aided spread because the flame is spreading in the same direction as the buoyant flow of gases. This wind-aided spread is generally much faster than the lateral and downward spread because of the larger sections of wall and ceiling being heated by the advancing flame front.

Flame spread on a fuel surface can be considered as a sequence of ignitions, as illustrated in Figure 3. An exposure fire or the flame from a segment of the material that is already burning imposes a heat flux on a fuel element that has not yet ignited. The temperature of this fuel surface element increases under the imposed heat flux. When a fuel element reaches its ignition temperature, the flame spreads to that fuel element, and it begins to burn. With this fuel element now burning, the flame grows longer and imposes a heat flux on the next fuel surface element. Some materials, such as thin combustible surface coatings or materials adhered to noncombustible substrates, burn out relatively quickly once ignited. Other materials, such as some wood products, char and consequently have a burning rate that decreases with time. Under some exposure conditions, such materials may not burn with sufficient intensity long enough to ignite subsequent fuel elements.

Upward flame spread on a fuel surface generally requires two conditions to occur:

1. The flame from the currently burning area of the fuel surface must extend beyond the burning area to expose the adjacent area to a heat flux high enough to ignite the adjacent area; and

2. The heat flux must be applied long enough to ignite the adjacent fuel surface.

To satisfy the first condition, the heat release rate per unit area of the burning fuel must be high enough to cause the flame to extend beyond the burning area. In general, the length of a flame along a vertical burning surface will be proportional to its heat release rate per unit width,[35] which in turn is proportional to the heat release rate per unit area. This can be expressed as:

$$x_f = k_f\left(\dot{Q}'\right)^n = k_f\left(\dot{Q}''x_p\right)^n \qquad (1)$$

where x_f is the length of the flame (m), measured from the base of the pyrolysis zone, x_p is the length of the pyrolysis zone (m), k_f is an appropriate flame length coefficient ($(\mathrm{m}/(\mathrm{kW/m})^n)$), $\dot{Q}'$ is the heat release rate per unit width (kW/m), and $\dot{Q}''$ is the heat release rate per unit area (kW/m^2) of the burning area of the fuel surface. According to this simple theory, the flame length must be greater than the pyrolysis length in order for flame spread to occur. Mathematically, this means that for flame spread to occur the following relation must hold true:

$$k_f\frac{\left(\dot{Q}''\right)^n}{x_p^{1-n}} > 1 \qquad (2)$$

Expressed differently, this also establishes the minimum heat-release rate per unit area for upward or wind-aided flame spread to occur:

$$\dot{Q}'' > \left(\frac{x_p^{1-n}}{k_f} \right)^{1/n} \qquad (3)$$

For example, Cleary and Quintiere[36] have suggested that k_f =0.01 m^2/kW and n=1 can be used to represent the flame length relationship, with a linear relationship between the flame length and the pyrolysis length. Based on these values, a heat release rate per unit area of $\dot{Q}'' \geq 100$ kW/m^2 would be needed for upward flame spread to occur. Tu and Quintiere[37] have also suggested that k_f =0.067 m$^{5/3}$/kW$^{2/3}$ and n=2/3 are appropriate values to represent this flame-length relationship. Based on these values, the minimum heat-release rate per unit area needed for upward flame spread would be $\dot{Q}'' \geq 58\sqrt{x_p}$ kW/m^2. Note that this value is a function of the pyrolysis zone length, with larger heat-release rates per unit area needed to sustain upward flame spread for longer pyrolysis zone lengths. This is one reason why some fires may burn out after spreading some distance up a wall. These relations are shown in Figure 4.

To satisfy the second condition, the burning duration, t_b, of the burning region must be greater than the ignition time, t_{ig}, of the exposed region. More specifically, the burning duration should be evaluated as the period of time that the burning region burns at a rate sufficient to achieve the first condition. In other words, the burning duration for the second condition would be the period of time during which the heat release-rate per unit area causes the flame length to exceed the pyrolysis zone length. In general, the burning duration can be evaluated as:

$$t_b = \frac{Q''}{\overline{\dot{Q}''}} = \frac{m''\Delta H_c}{\dot{q}''_{net,p}(\Delta H_c / L)} = \frac{m''L}{\dot{q}''_{net,p}} \qquad (4)$$

where Q'' is the energy content of the fuel surface per unit area (kJ/m^2), $\overline{\dot{Q}''}$ is the average heat-release rate per unit area (kW/m^2), m'' is the combustible mass per unit area (kg/m^2), L is the effective heat of gasification of the combustible mass (kJ/kg), and $\dot{q}''_{net,p}$ is the net heat flux to the fuel surface (kW/m^2) in the pyrolysis zone. For thermally thick surfaces, the time to ignition is generally represented, for a constant net heat flux at the fuel surface, as:

$$t_{ig} = \frac{\pi}{4} k\rho c \left[\frac{\Delta T_{ig}}{\dot{q}''_{net,f}} \right]^2 \qquad (5)$$

where the product $k\rho c$ is the thermal inertia of the solid surface ((kW/m^{2}K)^{2}s), ΔT_{ig} is the difference between the ignition temperature and the initial surface temperature (K), and $\dot{q}''_{net,f}$ is the net heat flux to the fuel surface in the flame region (kW/m^2). In general, the net heat flux terms in Equations 4 and 5 will not be equal to each other, but for this discussion they are assumed to be proportional to each other, i.e., $\dot{q}''_{net,f} = \chi_p \dot{q}''_{net,p}$. In general, the net heat flux in the pyrolysis zone is expected to be greater than the net heat flux in the flame zone, in which case the proportionality factor, χ_p, will have a value of less than one.

The burning duration expressed by Equation 4 can be equated with the ignition time expressed by Equation 5 to determine the minimum flame heat flux needed to cause ignition before burnout occurs. After some manipulation, this can be expressed as:

$$\dot{q}''_{net,f} > \frac{\pi}{4} \frac{\left(k\rho c \Delta T_{ig}^2\right)}{\chi_p \left(m''L\right)} \qquad (6)$$

Equation 6 would be difficult to evaluate quantitatively, particularly since the value of the proportionality factor is not known. Nonetheless, Equation 6 is useful for a number of reasons. First, it demonstrates that there is expected to be a minimum heat flux for flame spread for materials where fuel burnout is significant. Thus, it is important that such materials be tested under exposure conditions sufficient to exceed this minimum heat flux; otherwise, anomalous test results can occur when compared with actual field performance. This behavior has been observed for textile wall coverings, as noted above. Second, Equation 6 shows how different material properties are expected to influence the minimum heat flux for flame spread. Higher thermal inertias and larger ignition temperatures would be expected to increase the minimum heat flux for flame spread, while more fuel per unit area would be expected to lower it. Third, Equation 6 demonstrates the critical nature of flame spread, where a slight change in the heat flux or in the combustible mass per unit area (e.g., another coat of paint) can spell the difference between burnout and flame propagation. Finally, Equation 6 also shows that preheating of a fuel surface will tend to decrease the minimum heat flux for flame spread by decreasing the temperature rise needed to ignite the surface.

The relatively simple theoretical analysis presented here has identified a number of material properties and environmental conditions that are expected to influence flame spread on interior wall and ceiling finishes. The material properties include:

- *The thermal inertia of the material.* As shown in Equation 5, the thermal inertia of a material is directly proportional to the ignition time. Low-density materials tend to also have low thermal conductivities and consequently have very low thermal inertias. This is the primary reason why flame spread can be very rapid on exposed foam plastic products.
- *The ignition temperature of the material.* Although Equation 5 shows that the time to ignition varies with the square of the ignition temperature rise, ignition temperatures for most building materials fall within a relatively small range, so differences in ignition temperatures among materials do not affect flame spread nearly as much as the order of magnitude differences in thermal inertia do.
- *The combustible mass per unit area of the material.* This parameter is most significant for relatively thin coatings and materials on noncombustible substrates, such as painted or unpainted paper facers on gypsum wallboard or textile wall coverings adhered to gypsum wallboard, but is also important for materials that tend to char. Such materials are more likely to burn out locally and not spread a fire than materials with more combustible mass per unit area.
- *The ratio between the heat of combustion and the heat of gasification* $(\Delta H_c / L)$ *of the material.* As demonstrated in Equation 4, this "combustibility ratio" is directly proportional to the heat-release rate per unit area of a material and consequently has an influence on the flame length as well as on the total heat-release rate of the fire, which will have an influence on the preheating of fuel surfaces as well as the potential for flame extension beyond the room of origin.
- *The heat of gasification of a material.* While this property individually is not as significant as the "combustibility ratio," it does have an influence on the burning duration and consequently on the minimum heat flux for flame spread, as demonstrated by Equation 6.

The environmental parameters that influence flame spread on wall and ceiling finishes include:

- *The heat flux imposed on the fuel surface by an exposure fire.* This will influence the burning rate and the size of the fuel area first ignited, and consequently the flame length extending from this area and exposing adjacent fuel elements. By influencing the burning rate of the fuel, this parameter also influences the burning duration of this area. Ironically, a higher imposed heat flux may cause earlier burnout that a lower heat flux and consequently not cause flame spread under some conditions that a lower heat does.
- *The heat flux imposed by burning surface flames on adjacent fuel elements.* This will influence the time to ignition of these adjacent fuel surface elements and consequently the speed of flame spread.
- *The gas temperatures within the enclosure.* The accumulation of hot gases beneath the ceiling as a result of a fire causes preheating of the fuel surfaces in contact with the hot gases. As these surfaces heat up, the temperature rise needed to cause ignition decreases, resulting in shorter ignition times and lower minimum heat fluxes for fire spread. This effect will be most pronounced for materials that are good insulators, such as foam plastics and other low-density materials, because their good insulating qualities will result in higher gas temperatures as well as higher surface temperatures than more conductive materials will.

Based on this analysis, it should be apparent that flame spread on interior wall and ceiling finishes involves a number of complex interrelated processes, even for relatively simple geometries, homogeneous fuels, and well-characterized exposure conditions. It is for this reason that individual fire tests of interior finish materials may not be able to characterize their performance under a full range of field-use conditions.

PROPOSED EVALUATION METHODOLOGY

In 1978, Williamson and coworkers[34] suggested that "a standard room fire test could be used both as a development tool and a performance evaluation method until such time as a series of smaller, less expensive tests has been proven. Even then, new materials and systems which are different in principle from those already validated for small-scale fire tests would still require the full-scale test to show the applicability of small-scale tests." This is similar in concept to the evaluation methodology proposed here.

The evaluation methodology proposed here includes a preliminary screening/qualification step, followed by a more detailed analysis step. In the screening/qualification step, the flammability characteristics of a material are evaluated using a quantitative small-scale fire test method, such as the Cone Calorimeter or the FM Fire Propagation Apparatus. One of three outcomes will occur, depending on the performance of the material in the bench-scale test. These outcomes include:

- the material will be screened from any further consideration if it exhibits flammability characteristics recognized

Good performance – product qualified	**Intermediate performance – further testing required**	**Poor performance – product screened**
Low heat release rate per unit area (e.g., $\dot{Q}'' < 65\, kw/m^2$) or Time to ignition much greater than burning duration (e.g., $t_{ig} > 2 \times t_b$)	Intermediate heat release rate per unit area or Time to ignition similar to burning duration or Burning characteristics that cannot be evaluated in small-scale tests	High heat release rate per unit area (e.g., $\dot{Q}'' > 200\, kw/m^2$) or Time to ignition much less than burning duration (e.g., $t_{ig} < 0.5 t_b$)

Figure 4. General concept for flammability testing and evaluation.

to be unacceptable for the anticipated conditions of use;

- the material will be qualified as acceptable if it exhibits flammability characteristics considered to be fully acceptable for the anticipated conditions of use;
- the material will need to be subjected to additional large-scale testing, such as room fire testing, if its expected field performance cannot be adequately judged based on its bench-scale performance.

This concept is illustrated in Figure 4. The specific values of the different parameters to be used for screening or qualification will need to be evaluated along with the exposure conditions under which these parameters are evaluated. The values identified in Figure 4 are intended only as examples, although they are consistent with expected performance. ▲

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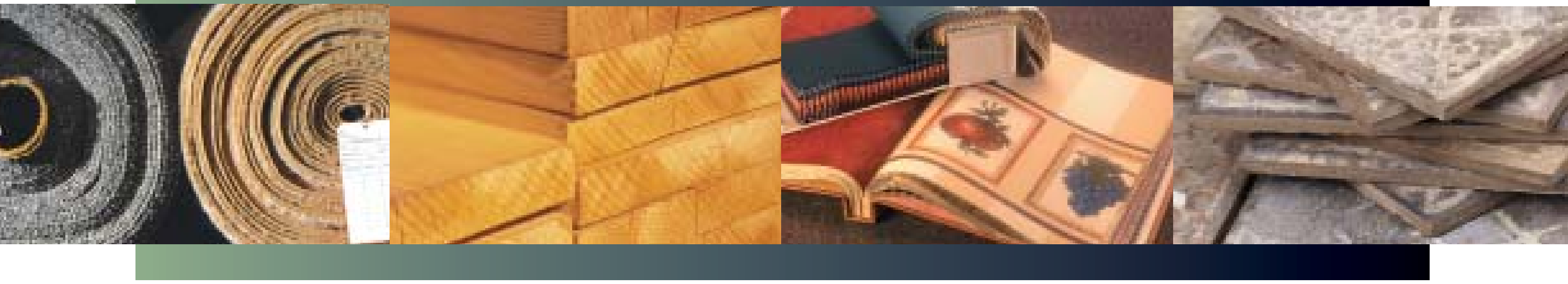
Assessing the Burning Characteristics of Interior Finish Material

Standard Test Method for Surface-Burning Characteristics of Building Materials ASTM E-84/UL 723



By Randy Laymon
Underwriters Laboratories Inc.

INTRODUCTION

Throughout history, structural fires have caused massive destruction and countless injuries and fatalities. Although the flammability characteristics of interior finish within these structures has played a major role in many of these losses, prior to the middle of the 20th century, fire protection of buildings focused primarily on: 1) the prevention of fire occurrence, 2) early detection and warning, 3) automatic or manual extinguishment, and 4) confinement with fire-resistant structural components, such as floors, ceilings, walls and partitions, columns, roofs, and doors.

The occurrence of major fires in individual buildings, distinguished by the rapid flame spread of interior finish materials, aroused public concern and demonstrated the need to address and regulate the burning characteristics of these materials. Specific material characteristics of concern included the spread of flame and the amount of heat generated and smoke developed. This led to the research and development of various testing protocols, most of which were small, laboratory-scale tests. However, based on work conducted by Albert J. Steiner at Underwriters Laboratories Inc., from the early 1920s through the 1940s, the 25 ft. (7.6 m) long Steiner tunnel emerged as the predominant method to characterize and regulate the surface-burning characteristics of interior finish materials.

The Steiner tunnel is a furnace chamber that measures flame spread and smoke development. Its prominence in the fire protection community was based on its ability to provide cost-effective, repetitive testing and use a sample size that could better characterize interior finish materials used in actual installations. This method is currently described in UL 723,[1] *Test for Surface Burning Characteristics of Building Materials*, as well as ASTM E-84[2] and NFPA 255.[3]

SUMMARY OF TEST METHOD

The Steiner tunnel is used to assess the comparative surface-burning characteristics of building material samples with the exposed area measuring 18 in. (460 mm) wide by 24 ft. (7.3 m) long, up to a thickness of approximately 5-6 in. (125-150 mm). The test is conducted with the sample mounted in the “ceiling” position of an enclosed tunnel furnace measuring 18 in. (460 mm) wide by 12 in. (300 mm) deep by 25 ft. long (7.6 m). A nominal 5000 Btu/min. (88 kW), 4-1/2 ft. (1.4 m) flame provides an ignition source to the underside of the mounted specimen for a 10-minute duration. A controlled inlet draft of 240 feet per minute (1.2 meters/second) facilitates horizontal flame propagation throughout the test. A light and photoelectric cell mounted in the exhaust duct record smoke obscuration during the test. Flame-spread and smoke-developed indices are reported in comparison with calibration materials of red oak lumber and inorganic reinforced cement board. Red oak propagates flames to the end of the tunnel in 5 minutes 30 seconds ± 15 seconds and generates a flame-spread index of approximately 90. A smoke-developed index of 100 is assigned for red oak. Inorganic reinforced cement board generates flame-spread and smoke-developed indices of zero.

EARLY HISTORY AND DEVELOPMENT

The initial version of the tunnel furnace was developed in 1922 when Mr. Steiner, an engineer in UL’s Fire Protection Department, assessed the effectiveness of a “fireproof” paint. The prototype test method consisted of a long wooden bench measuring approximately 18 in. (460 mm) in width and depth and 16 ft. (4.9 meters) long with a noncombustible top. The interior of the tunnel was coated with the paint under investigation and ignited with a given quantity of wood at one end. The extent of the spread of flame was compared with an unpainted replica, and the flame retardancy of the coating was thus evaluated.

In the late 1920s, the development of pressure-impregnated fire-retardant lumber, in conjunction with further research at UL, led to modifications to the test method in which the test sample formed the top of a 36 in. (91 mm) wide by 13 in. (330 mm) deep by 23 ft. (7.0 m) long chamber. The use of untreated red oak and maple flooring in this investigation was a major factor in the selection of red oak as one of the calibration materials for the test method.

By the beginning of World War II, there was growing interest in reducing the combustibility of existing materials through various treatments and in measuring the flammable properties of new materials. In addition, by the mid-1940s, a number of disastrous fires occurred, including the Cocoanut Grove nightclub fire in Boston in 1942 and the Chicago LaSalle Street Hotel and Atlanta Winecoff Hotel fires, both in 1946. In all, 670 people perished in these three fires alone. The magnitude of the fire fatalities in each of these fires was directly related to the rapid flame spread and smoke development of the interior finish materials. These findings highlighted the need to test and classify materials on a scale that would measure the three essential material characteristics previously identified: flame spread, fuel contributed, and smoke developed. All these factors led to the evolution of the current tunnel apparatus. It was at this time that the Surface-Burning Characteristics Classification Scale was first defined. It was essential that, in order to classify materials according to the properties of flame spread, fuel contributed and smoke developed, as well as to have this information be of value, a comparative scale was required. Accordingly, the test initially developed a classification for each of these properties for a sample material on a comparative scale with a combustible (red oak lumber) defined as 100 and a noncombustible cement board as zero.

The current physical version of the tunnel was completed in the late 1940s. Many controls were implemented to enhance repeatability and reproducibility. The standard specimen size became 20 in. (510 mm) wide by 25 ft. (7.6 m) long. The ignition source was adjusted to obtain a nominal 4-1/2 ft. (1.4m) long, 5000 Btu/min. (88 kW) test flame that generates gas temperatures of approximately 1200°F to 1600°F (650°C-870°C) near the specimen surface at the ignition end of the test sample. The inlet draft was established at 240 feet per minute (1.2 meters/second).

The method used to calculate Flame Spread Index (FSI) has undergone some modifications over the years. Originally, the FSI was based on the ratio of the time at which flames traveled the full tunnel length or the partial flame travel distance relative to that of red oak. In 1976, the FSI was changed to a time-flame spread distance area basis. The current method is still based on a time-distance area calculation but incorporates a rate of flame travel as well.

Prior to 1978, a Fuel Contributed Index was reported. This index was based on air temperatures developed within the tunnel furnace during testing. In 1978, the Fuel Contributed Index was deleted from the method since it was recognized that the value did not provide a valid measure of fuel contribution.

COMMUNITY ACCEPTANCE

Just as the test method developed gradually over a period of years, so did its acceptance. The test method was first published in 1950 by Underwriters Laboratories Inc. as Standard UL 723. ASTM followed by publishing the test method as a tentative standard in 1950 and as a formal Standard, ASTM E-84, in 1961. NFPA adopted the test method as NFPA

255 in 1955. It was adopted by ANSI in 1963 as American National Standard A2.5.

Although the tunnel test provides for a Classification protocol and is recognized by standards-developing organizations, it does not establish limitations for building codes. The intent of the test method is to provide a tool for those with the responsibility of regulating materials used as interior finish in buildings. Widespread reliance on the tunnel test method by the regulatory community as an acceptable criterion to assess interior finish and other materials has been in place for decades. Factors that have contributed to this reliance include:

- Support by standards-developing organizations, including UL, ASTM, and NFPA.
- The test method utilizes a large sample size and an ignition source representative of a moderately developed fire scenario.
- The ability of the test method to characterize both high and low flame spread materials.
- Research that demonstrates a relationship between tunnel test results and certain large-scale test protocols.[4]

Interior finish requirements are currently defined in Chapter 8 of the *International Building Code*[5] and Chapter 10 of NFPA 5000, *Building Construction and Safety Code*.[6] Interior finishes are grouped in the following classes in accordance with their flame-spread and smoke-developed indices.

Class A: Flame Spread 0-25; Smoke Developed 0-450.
Class B: Flame Spread 26-75; Smoke Developed 0-450.
Class C: Flame Spread 76-200; Smoke Developed 0-450.

Prior to 1960, the tunnel test method was used primarily for the evaluation of the surface-burning characteristics of homogenous compositions of ceiling and wall finishes, such as acoustical tiles, wall coverings, coatings, and various types of decorative paneling. Through inclusion of the *Guide to Mounting Methods Appendix* in the late 1960s, the method was expanded to include the evaluation of composites and assemblies. Sample mounting techniques can have a significant influence on the fire-performance indices developed by the test method. While the *Appendix* is not considered a mandatory part of the standard, the *Guide* has proven useful in promoting more-consistent results by various laboratories. Recently, a more comprehensive approach toward the standardization of mounting practices has led to the development of ASTM E2231, *Standard Practice for Specimen Preparation and Mounting of Pipe and Duct Insulation Materials to Assess Surface-Burning Characteristics*. Similar practices for other material types are currently being considered under the ASTM standard-development process.

ADVANTAGES AND LIMITATIONS

- Certain relationships have been observed between Steiner tunnel test results and performance of some materials during building fires.[2]
- The test method provides for a realistic fire scenario by presenting a sample of sufficient size to allow for progressive surface burning over a large exposed area.
- A wide range of materials may be tested, including composite constructions, coatings, faced products, loose-fill materials, sandwich panels, and many others. UL currently classifies over thirty different product types in accordance with the test method.
- The test method provides a means to discriminate products yielding a wide range of flame-spread and smoke-developed characteristics, allowing for the development of codes and standards.
- Some research conducted has demonstrated useful relationships between Steiner tunnel flame-spread values and fire performance of materials in large-scale corner configurations using a 20-pound ignition source wood crib.[4]
- The horizontal specimen orientation places some limitation on the type of material that can be realistically mounted. Depending on the particular material being tested, specimens requiring additional support may yield low flame-spread values due to the supporting material restricting flame propagation or high-flame spread values because the additional support retains the specimen in the ceiling position rather than allowing the specimen to fall away from the area of flame impingement.
- Some materials, such as faced composite samples, may delaminate during testing, which may result in one of two possible responses: the material may expose two or more surfaces to the flame, thereby increasing the flame spread index; or the material may sag or drop to the furnace floor, which may impede further flame propagation.
- Thermoplastic materials may be difficult to evaluate in this as well as other standardized fire test procedures and require careful interpretation of the test results. These materials tend to melt and drip to the floor of the furnace, and may generate potentially misleadingly low flame-spread values.
- Some research has indicated that some types of thermosetting cellular plastics yielding low flame-spread values may generate flameover conditions during certain large-scale room test scenarios, when utilizing igniting sources of sufficient heat flux levels.[4]

No single test method provides the total information necessary to completely evaluate the potential for fire development in a building, yet each makes some contribution to the total body of knowledge required. The Steiner tunnel test method is the most extensively used and referenced test method to assess flammability of interior finish materials. The results form a basic element in regulation of these materials by providing an identification system for inspection and enforcement authorities. ▲

Randy Laymon with Underwriters Laboratories Inc.

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Resources

New Additions to the SFPE 2004 Publications Catalog

The Code Official's Guide to Performance-Based Design Review

The use of performance-based design is becoming more prevalent as new performance-based codes and guidelines are developed and adopted. This can create challenges for enforcement officials or other stakeholders if they do not have a strong background in performance-based design or if their resources are already stretched thin. This guide identifies the types of items that an enforcement official should consider when reviewing a performance-based design. The concepts identified in this guide are applicable to performance-based fire protection designs that are prepared to meet performance-based codes, designs that are prepared as equivalencies to prescriptive-based code requirements, and designs that are intended to meet objectives that exceed those contained in a code or standard (e.g., business interruption, protection of contents, etc.) ISBN 1-58001-202-7, 113 pages.

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UPCOMING EVENTS

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Computational Simulation Models in Fire Engineering and Research

Santander, Spain

Info: grupos.unican.es/gidai

November 16-17, 2004

International Symposium on Tunnel Safety and Security

Greenbelt, MD

Info: www.ni2cie.org

November 29-30, 2004

Fire Risk Evaluation to European Cultural Heritage

Ghent, Belgium

Info: www.firetech.be

December 6, 2004

Symposium on Firestopping

Washington, DC

Info: www.astm.org

Through December 2, 2004

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In various cities in the U.S., please see Web site for dates, times, and places.

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Fire Alarm Systems and Interior Finish – A Balanced Approach

What is the relationship between a fire detection and alarm system and the interior finish of a space? Fire protection is not any one system but a balance between many systems and concepts. This article looks at the role of fire detection and alarm systems as a part of a balanced fire protection system. From an analysis point of view, when one facet of fire protection changes, the performance of other systems may be affected. From a design perspective, if the expected performance of one system changes, then others may be required to change in order to maintain the expected level of prevention or protection.

In this article, interior finish is used as a variable; see how fire detection and alarm systems must change to maintain balance when some other system (interior finish) changes. Though the link is not a strong one, it is useful to demonstrate how different systems interact with each other. How does a fire detection and alarm system affect the selection of interior finishes? What effect does interior finish have on the design of a fire detection and alarm system?

BALANCED PREVENTION AND PROTECTION

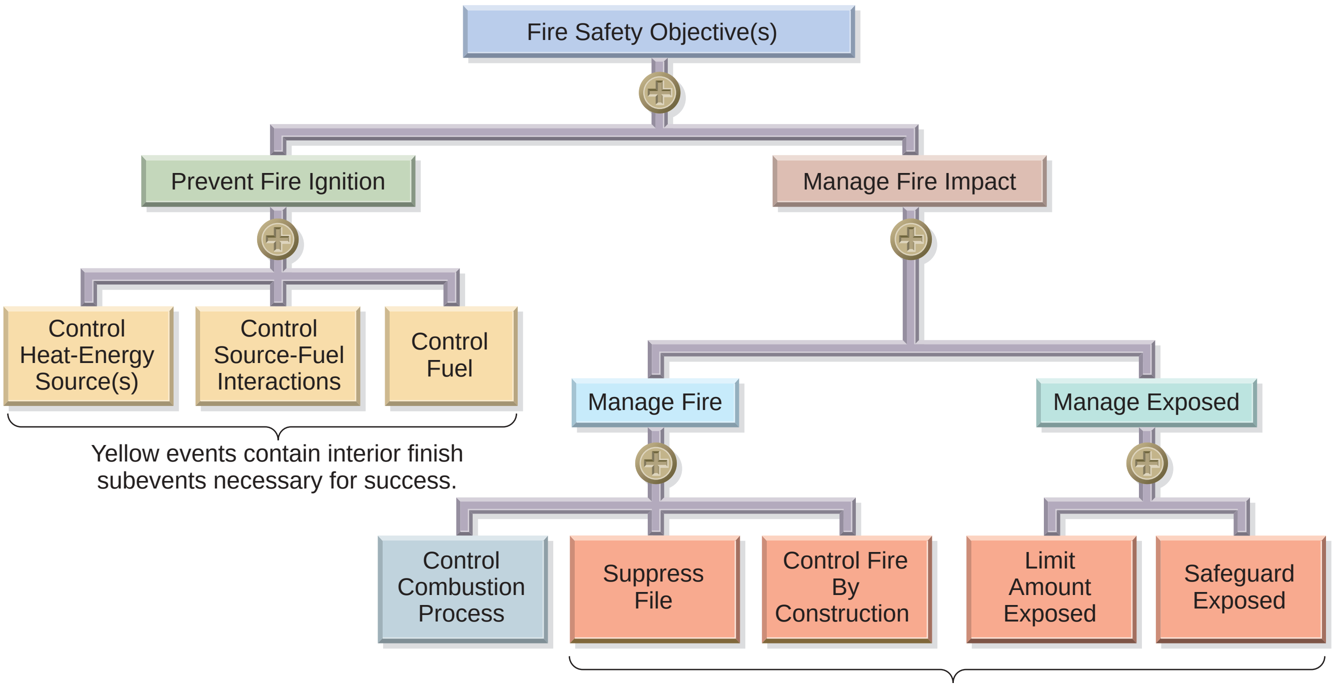
Model building and fire codes contain specific limitations on interior finish. Some occupancies or use groups are permitted to have combustible interior finishes with higher flame spread and smoke production characteristics than other occupancies or use groups. For example, the 2000 *International Building Code (IBC)* restricts the flame spread and smoke production ratings of interior finish used in the egress components of unsprinklered apartment buildings to Class B (flame spread 26-75; smoke developed 0-450)[1]. Class A (flame spread 0-25; smoke developed 0-450) materials are required in Assembly occupancies while Class C (flame spread 76-200; smoke developed 0-450) materials are permitted in one- and two-family dwelling units.

The restrictions on interior finish are based, in part, on:

- the expected/permitted occupant load
- occupant mobility
- the maximum permitted travel distance
- the degree of compartmentation
- the presence or lack of automatic suppression systems
- the presence or lack of automatic detection and alarm systems

The above list can be transformed, placing any one of the bullet items at the top as the dependent variable. For example:

The requirements for fire detection and alarm in a building are based, in part, on:



Yellow events contain interior finish subevents necessary for success.

Orange events contain fire detection and alarm subevents necessary for success.

Figure 1. Fire Safety Concepts Tree

- the flame spread and smoke potential of the interior finish
- the expected/permitted occupant load
- occupant mobility
- the maximum permitted travel distance
- the degree of compartmentation
- the presence or lack of automatic suppression systems

Building and fire codes specify certain combinations of the various systems necessary to meet the objective of the code. For example, in the 2000 *IBC*, Assembly occupancies are permitted to have Class B interior finish in egress components when sprinkler protection is provided. When there is no sprinkler protection, the interior finish is limited to Class A. The code does not list any similar tradeoffs for interior finish when an automatic fire detection and alarm system is incorporated. A performance based analysis/design may permit greater latitude in combining various degrees of each protection or prevention system. Unlike complete automatic suppression, fire detection and alarm system improvements by themselves are not likely to permit changes in interior finish, particularly in egress paths. However, by improving fire detection and several other facets of protection, such as decreased travel distance, reduced occupant load, more than two egress paths from a space, and improved containment of fire and smoke, it may be possible to use some combustible finishes. For instance, it may be acceptable to use wood paneling as a wainscoting in limited horizontal exit access corridors. Or in rooms (not part of the egress system) that might normally require Class B or better interior finish, supplementary fire detection that closes fire and smoke doors and initiates smoke control may allow the use of Class C finishes.

The relationships and interdependencies among these various parts of balanced fire protection are complex. Codes typically contain one or two simple, reliable, proven combinations of systems to achieve a fire safety objective. Other possible solutions may also be possible, but may incorporate more complex combinations and relationships. NFPA 550, *Guide to the Fire Safety Concepts Tree*, is a useful tool for examining these relationships and their weighted impact on fire safety.[2] The Fire Safety Concepts Tree is an event tree using logical AND and OR gates to relate various combinations of subevents that lead to the top level successful event. Figure 1 is the top level of the Fire Safety Concepts Tree.

Note that the top-level *Fire Safety Objective* is connected by an OR gate (circle with a plus sign in it) to the subevents *Prevent Fire Ignition* and *Manage Fire Impact*. If probabilities are calculated or designated for the subevents, then the OR gate dictates that the probabilities be added together to determine the probabil-

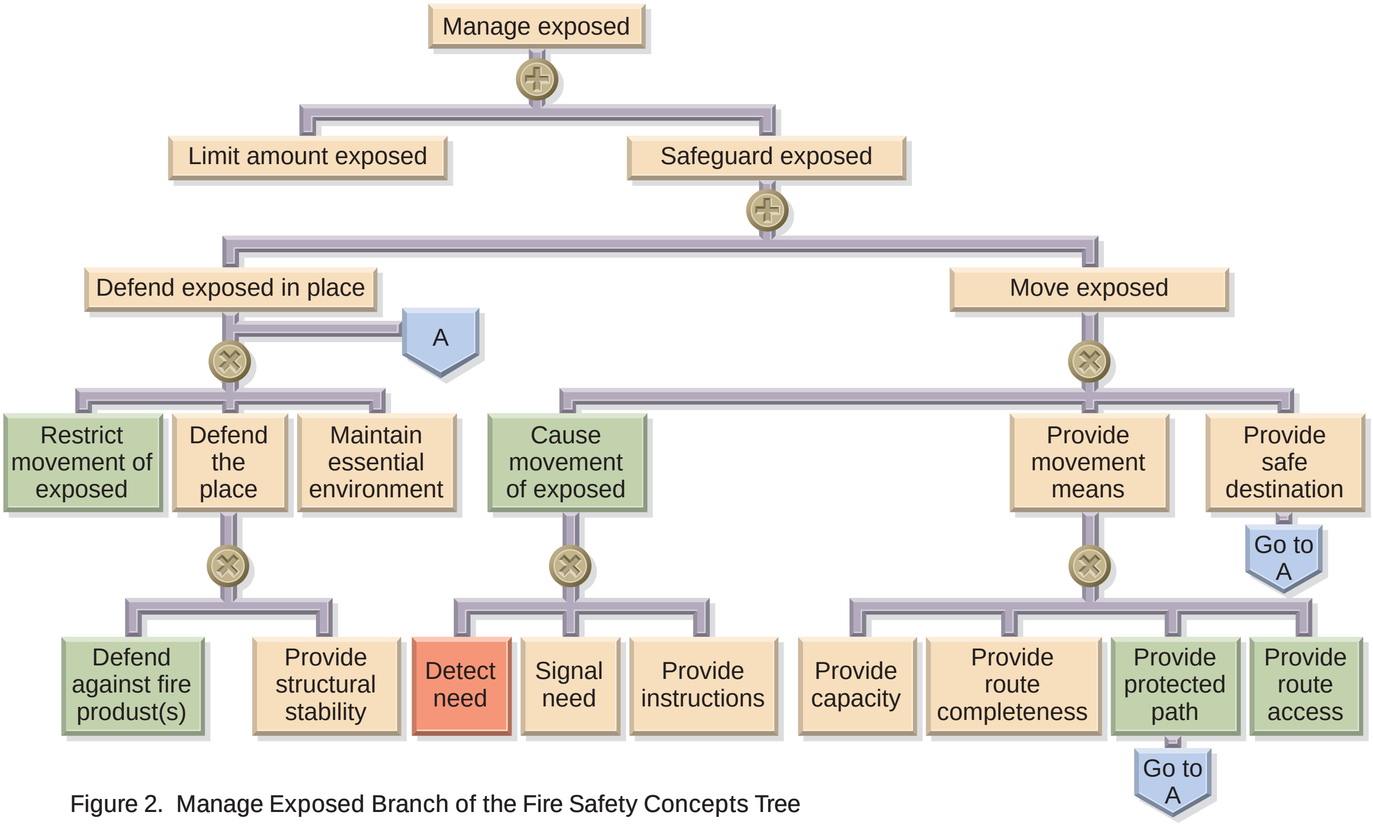


Figure 2. Manage Exposed Branch of the Fire Safety Concepts Tree

ity of the parent event. That is why the OR gate symbol is a circle with a plus sign in it. In other parts of the Fire Safety Concepts Tree AND gates (circle with an X or a dot in it) require all subevents to occur. Thus, the probabilities are multiplied to determine the probability of the top-level event.

The entire Fire Safety Concepts Tree is too large to reproduce in this short article. However, examination of the remainder of the tree shows that paths containing events related to interior finish fall under both the *Prevent Fire Ignition* event and the *Manage Fire* event. Fire detection events are found only under paths leading to *Manage Fire Impact*. In Figure 1, the red event boxes contain paths that eventually lead down to a detection event box. The yellow events contain paths that relate to interior finish. The purple box leads to both fire detection and interior finish events.

The Fire Safety Concepts Tree explicitly lists three *Detect Fire* events that lead upwards in the tree to the *Manage Fire Impact* event box. However, they all connect through AND gates. This means that success is also dependent on other events taking place. For instance, fire protection engineers regularly *Manage Fire Impact*, by *Moving the Exposed*. In addition to detecting the fire, it must be signaled to occupants and emergency forces, adequate egress means must be provided, and a safe destination is also needed.

Fire detection is also a part of several other Fire Safety Concepts Tree events, though not specifically listed. For example, instead of *Moving the Exposed*, a design might include the event *Defend Exposed in Place*. (See Figure 2.) One element required to accomplish this is to maintain a tenable environment. In the Fire Safety Concepts Tree, this event is titled *Maintain Essential Environment*. The tree does not show subevents required for that event. In some cases, it is useful to add additional subevents to understand what is required for an event to be successful. One subpath might include fire detection AND closing dampers. Another subpath might be fire detection AND pressurization of a space. In Figure 2, events that might contain detection subevents are shown in green.

PERFORMANCE EFFECTS

Interior finish has several direct effects on the design and performance of fire alarm systems. The most obvious is on the selection and performance of audible signals. Building materials such as glass, carpet, and acoustical tiles are tested to determine their sound absorption coefficients at different frequencies.[3] A particular drop ceiling panel may have a relatively flat absorption curve. That is, its absorption coefficients are about the same for low, middle, and high frequencies. Sound that is not absorbed is reflected back into the room or space. Materials such as glass and gypsum board tend to have higher absorption coefficients at the lower frequencies and lower absorption at the higher frequencies. Thus, they tend to reflect more of the high-frequency sound. Carpeting and some acoustical tiles absorb high frequencies much more efficiently than lower frequencies.

With tone-only signals, materials that are acoustically hard with respect to higher frequencies cause a large amount of the higher-frequency sound energy to bounce off of the surfaces and fill a space. This helps distribute the audible signal in a space, particularly when using today's higher-frequency appliances that operate at approximately 3000 Hz.

High-frequency signals, such as those generated by the piezo electric transducers used in many modern fire alarm audible appliances, tend to be more directional than lower frequency signals.[4, 5] Thus, they are not as loud at one side of the device as compared to in front of the device. In acoustically hard environments, directionality is less important because of reverberation. On the other hand, acoustically soft surfaces absorb more of the fire alarm sound energy and help prevent it from reverberating and filling a space. Therefore, in acoustically soft spaces, directionality may affect loudness in some locations. So, building materials and interior finish that absorb high frequencies may require the use of a larger number of audible appliances. They are spaced to ensure that listeners are always located in the direct field of the sounder.

When voice is used as the fire alarm signal, acoustically hard surfaces help maintain audibility of the voice but cause reverberation, decreasing the intelligibility of the voice message.[6] That is one reason why it is necessary to measure the intelligibility of voice systems, not just the audibility. In acoustically soft spaces, any reverberation is generally at a much lower energy level (not as loud). Therefore, persons generally need to be in the direct field of a speaker to receive an intelligible message since the volume will be too low at other locations.

The color of interior finish and the ambient lighting of a space affect the signal-to-noise ratio of fire alarm strobe lights. The current requirements of NFPA 72 (soon to be adopted directly as part of the Americans with Disabilities Act Accessibility Guidelines) are based on research by Underwriters Laboratories (UL) using indirect signaling in relatively small spaces such as classrooms and offices.[7, 8] The tests and resulting guidelines for strobe signaling were based on a variety of conditions, including light and dark surfaces with high and low ambient lighting. Thus, NFPA 72 requirements should cover most situations in small spaces. However, the effect of high ambient light with bright interior finishes in large spaces has not been studied and may be beyond reasonable extension of the UL test results.

Interior finish can also directly impact the success of a fire detection system. To be successful, a fire detection and alarm system must do its job before an attack by fire causes the system to fail. If circuits pass through spaces with combustible interior finish or combustible occupant-related goods but without fire detection, they can be attacked, and they may fail before successful fire detection takes place. Similarly, even where detectors are present, if the system does not remain operational long enough to complete its mission, failure occurs. Thus notification appliance circuits may need to be protected and additional fire detection may be warranted. Circuits installed on or directly behind combustible finishes may not survive long enough to do their job.

Fire prevention and fire protection strategies require that many different systems work together (balance), and in some cases, they must be coordinated so that they do not interfere with each other (performance).[9] While the relationship between interior finish and fire detection and alarm systems is a relatively weak one, they still impact each other. Stronger relationships exist between interior finish and egress, and between fire detection and smoke control, for example.

NFPA's Fire Safety Concepts Tree provides a logical graphical format to understand the many facets of fire safety and the relative impact each may have on a stated goal. In some cases, it is useful to expand the tree to provide additional detail and analysis capability.

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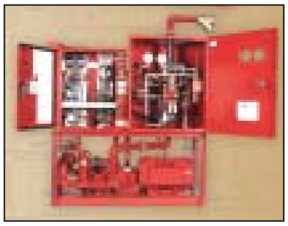
Editor's Note – About This Article

This is a continuing series of articles that is supported by the National Electrical Manufacturer's Association (NEMA), Signaling Protection and Communications Section, and is intended to provide fire alarm industry-related information to members of the fire protection engineering profession.

Products/Literature

Prepiped Mist Protection



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Two new fire alarm power supply products – the HPF602ULADA and the HPF902ULADA – connect to virtually any fire alarm control panel to provide the additional power needed for notification appliance circuit expansion. They cost-effectively deliver significant power and built-in synchronization protocols for many common strobes.

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BRAINTEASER

Yahtzee® is a game played with five six-sided dice. Players take turns rolling the dice, trying to get certain combinations of 1s, 2s, 3s, etc. Players may roll the dice up to three times during each turn and are permitted to set aside any subset of the five dice after each roll.

A player rolls the following combination on the first roll: 2, 2, 3, 4, 5. If the player keeps the 2, 3, 4 & 5, what is the probability of obtaining a "large straight" (the numbers of all five dice fall in a consecutive sequence) in the two remaining rolls?

Solution to last issue's brainteaser

Substitute a unique integer from 1 to 9 for each different letter in the subtraction problem below.

$$\begin{array}{r} \text{FIRE} \\ \underline{-\text{HEAT}} \\ \text{OUT} \end{array}$$

There are at least three solutions:

$$\begin{array}{r} 2598 \\ \underline{-1834} \\ 764 \end{array}$$

$$\begin{array}{r} 6198 \\ \underline{-5824} \\ 374 \end{array}$$

$$\begin{array}{r} 9126 \\ \underline{-8673} \\ 453 \end{array}$$

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from the technical director

The Continuing Need for Fire Research

Morgan

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Beginning with the publication of the *SFPE Handbook of Fire Protection Engineering* and continuing with the publication of performance-based codes and several engineering design guides, the fire protection engineering profession has matured tremendously over the past decade-and-a-half. Underpinning this advancement is a foundation of fire research. However, a great deal of this research was conducted in the 1950s through the mid-1980s. While quality research continues, significantly less funding is available to support this research, and hence, much less is being conducted now than before.

Before proceeding further, it is useful to define the term “research” as used here. “Research” refers to a scientific investigation which has results that can be broadly applied in engineering practice. This differs from “testing,” which is frequently applied to solve specific problems and which is typically not readily applied in a general sense.

Underlying the decline in research productivity has been a decline in funding of national government laboratories. Several governmental fire laboratories have been privatized, with the result that funding for research must be sought from the private marketplace, where interest tends to favor testing over fundamental research. Public fire laboratories that were not privatized have suffered a diminishing level of funding from their national governments. For example, government-appropriated fire funding at the U.S. National Institute of Standards and Technology (NIST) rose from approximately four million dollars in 1974 to about seven million dollars in 1999. While this may seem like an increase, it actually represents a decrease in purchasing power of approximately 50% due to a decline in the value of the dollar. While NIST has received additional funding to analyze the building failures that occurred on September 11, 2001, this funding increase may be only temporary.

Fire protection engineering is the bridge between fire research and the built environment. A fundamental tenet of engineering is to do the best job possible with the information that is available, and despite declining research productivity, fire protection engineers will continue to apply the knowledge available to protect people and property from fire. When faced with a less-than-total understanding in an area of practice, engineers typically compensate by building in conservatism. This excess conservatism translates into higher design costs, which are ultimately passed on to the public through higher overall costs of products and services. With an improved understanding of the science of fire, engineers could safely reduce excess conservatism while still providing an appropriate level of safety. Additionally, continued research would expand the types of problems that fire protection engineers could solve.

The Society of Fire Protection Engineers has focused some efforts in countering this trend. SFPE held a workshop in 1999 to develop a research agenda for the fire protection engineering profession (available from *www.sfpe.org/sfpe30/pdfsanddocs/pbdfr.pdf*). While broad in scope, this research agenda indicates the types of research that engineers could use to benefit society.

One of the conclusions reached during the development of the research agenda was that the public sector alone will likely not return to the state of research funding during the mid- to late 20th century. Public/private partnerships will be necessary to increase the amount of research funding that is available. While not identified in the research agenda, the first step is the development of a sound business plan to attract funding to support fire research.

SFPE has also directly supported research through its Educational and Scientific Foundation. The Educational and Scientific Foundation has historically supported a number of fire research projects, typically conducted at academic institutions. Funding for this support has come from contributions from SFPE members and chapters. Additionally, the Foundation is currently exploring mechanisms to expand its support.

While relatively modest in magnitude, the Educational and Scientific Foundation made valuable contributions since its 1979 inception, and this support has the potential to grow. A sound foundation of fire research allows fire protection engineers to provide the best possible service to the public, clients, and employers.